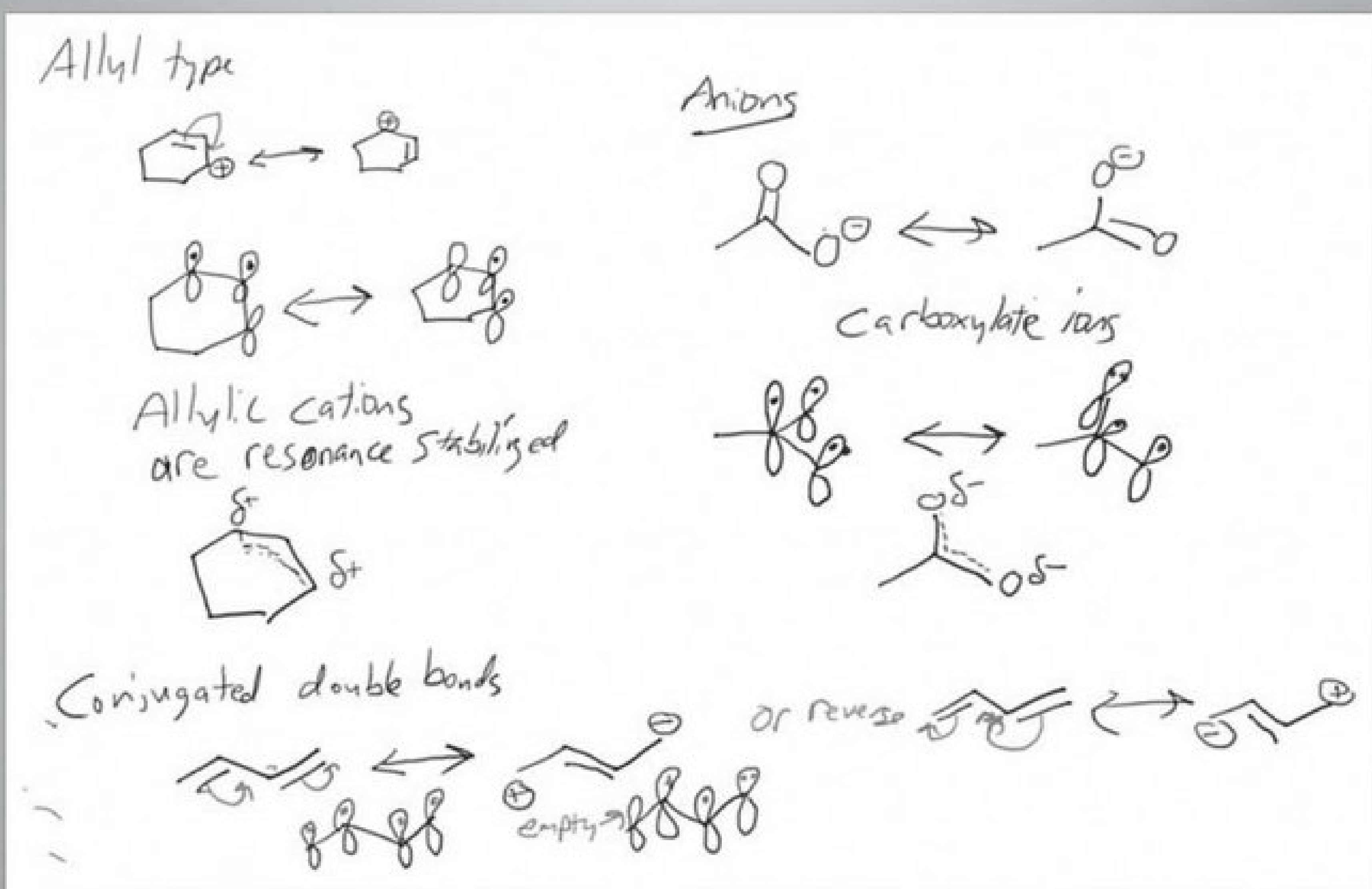
ACS SYMPOSIUM SERIES 1223

The Flipped Classroom

Volume 1: Background and Challenges



Jennifer L. Muzyka and
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Foreword

The ACS Symposium Series was first published in 1974 to provide a mechanism for publishing symposia quickly in book form. The purpose of the series is to publish timely, comprehensive books developed from the ACS sponsored symposia based on current scientific research. Occasionally, books are developed from symposia sponsored by other organizations when the topic is of keen interest to the chemistry audience.

Before agreeing to publish a book, the proposed table of contents is reviewed for appropriate and comprehensive coverage and for interest to the audience. Some papers may be excluded to better focus the book; others may be added to provide comprehensiveness. When appropriate, overview or introductory chapters are added. Drafts of chapters are peer-reviewed prior to final acceptance or rejection, and manuscripts are prepared in camera-ready format.

As a rule, only original research papers and original review papers are included in the volumes. Verbatim reproductions of previous published papers are not accepted.

ACS Books Department

Chapter 1

Introduction

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The flipped classroom is a hot topic not only among educators but also in the general public, with articles in the USA Today, Washington Post, and New York Times. Bergman and Sams' *Flip Your Classroom* brought this pedagogical approach to the attention of chemistry educators. At the 2012 Biennial Conference on Chemical Education (BCCE) there were two presentations on the flipped classroom. In 2014 there were three symposia focused on the flipped classroom – the national ACS meeting in Dallas, the spring ConfChem, and the BCCE, which had four completely full sessions. We are happy to share this group of papers from the BCCE symposium where half of flipped courses described are general chemistry courses, one quarter of the courses are organic, and the last quarter include analytical, biochemistry, physical chemistry, and general/organic/biochemistry (GOB).

The flipped classroom has become the new buzzword not only among educators but also in the general public, with articles in the USA Today (*1*), Washington Post (*2*), and New York Times (*3*). Bergman and Sams' *Flip Your Classroom* (*4*) brought this pedagogical approach to the attention of chemistry educators in 2012. At the 2012 Biennial Conference on Chemical Education (BCCE) there were two presentations on the flipped classroom. In 2014 there were three symposia focused on the flipped classroom – the national ACS meeting in Dallas, the spring ConfChem (*5*), and then at the BCCE, which had four

completely full sessions. With this growth, we are happy to have this opportunity to share a collection of papers from the 2014 BCCE symposium.

The most recent Higher Education Research Institute (HERI) survey (2013-14) indicates that faculty members' use of extensive lecturing has wavered around 55 to 60 percent since 1989 (*6*). The fraction of college and university faculty members who expect students to learn before lecture (e.g., flipping the classroom) is small, around 20-21 percent. It is not known whether the percentage of chemistry faculty who flip is the same as in the survey, which included all disciplines. In the chemistry literature, about half of the flipped courses are in general chemistry, one fourth are organic, and the last fourth include analytical, biochemistry, GOB, and physical chemistry.

Chemists who teach in flipped classrooms embrace a variety of learning theories to guide their implementations. Most chemists who use active learning approaches in their classrooms value some aspect of constructivism theory (*7*), in which learners must begin their understanding of the concepts in their pre-class assignments. Later, students apply the concepts in class using active learning methods. Further theory is described by Bishop as he points out the unusual juxtaposition of contructivism (active learning) with behaviorialism embraced by instructors who have students watch video lectures before class (*8*). Additionally, some chemists who teach flipped classrooms explicitly embrace the cognitive load theory, recognizing that an introduction to key terms in the pre-class assignments facilitates student learning (*9*).

History

Simply stated, the flipped classroom is a high tech variation on a pedagogical method that has been around for generations. The time honored Socratic method aims to actively engage students with instructors asking them questions, leading them down a path where they are encouraged to see the connections between ideas (*10*). Additionally, flipped classrooms resemble the Thayer method, used at the United States Military Academy since the early 1800's (*11*), which expects cadets [students] to take responsibility for their own learning by studying material before it is covered in class.

Current facets of the flipped pedagogy appear when Morrison and Boyd's *Organic Chemistry* textbook was published in 1959. At that time, Morrison realized that the students had his classnotes in the form of a book (*12*). He soon learned about the Gutenberg method from Frank Lambert's presentation at a meeting in Atlantic City. In this method, the students read an assigned text before class. When class meets, the students are prepared with questions about the material so that students and instructors can have a meaningful discussion about the concepts rather than students acting as stenographers.

David Johnson and colleagues had been studying cooperative learning in college courses since the 1970's (*13*). Alison King introduced the phrases "sage on the stage" and "guide on the side" in 1993, as she wrote about the status of active learning in college classrooms (*14*). Cooperative learning in small groups is another fundamental component to most of the flipped chemistry classrooms

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described in this collection. What we know as the flipped classroom is the combination of these content strategies with active learning, enhanced with technology such as videos or online quizzes before class.

Audio and videotapes of chemistry lectures were being used in courses as far back as 1970 (*15*). In the mid-1990's, colleges and universities were creating campus networks to share resources. In 1995, Wesley Baker flipped his communications courses by posting his PowerPoint slides on the Cedarville College network (*16*). Baker described his approach at a conference in 2000 (*17*). Also in 2000, Lage and colleagues described their approach to inverting the economics classroom (*18*, *19*). The flipped/flipping term became broadly used in 2012 when Bergman and Sams published *Flip your classroom: reach every student in every class every day* (*4*).

Chemists have been discussing the use of active learning methods in classes since 1980 (*20*), shortly after Piaget's work was described in the *Journal of Chemical Education* (*21*, *22*). Students in active learning classrooms strengthen their skills of self-assessment as well as peer assessment (*23*). Cooper and colleagues have reported that students' problem-solving skills are improved when the students work in collaborative groups (*24*). Jensen argues that any benefit observed in flipped classrooms is due to the active learning methods used in the flipped classrooms (*7*). Several reviews have summarized the evidence supporting the value of active learning (*25–27*). Bishop and Verlager recently reviewed the variety of approaches used in flipped classrooms (*8*). A recent review by Seery focuses on the use of flipped classrooms in chemistry courses (*28*).

This Book (Volumes 1 and 2)

For this book, we define the flipped classroom as one where students gain exposure to course content before class and the face-to-face time involves active learning. Bishop and Verlag exclude pre-class reading assignments from their definition of flipped classrooms, explaining that students are not likely to read the relevant textbook material before each class (*8*). We include pre-class reading assignments such as Just-in-Time Teaching, which specifically incorporates methods that hold students accountable for their reading assignments (*29–33*). Other terms and different pedagogical methods are in use for approaches that fit our definition of the flipped classroom, including: the inverted classroom (*18*, *19*, *34*), peer instruction (*35*), upside-down classroom (*36*), blended learning (*37*), hybrid classes (*38*), and pre-class preparation (*39*, *40*). Most instructors use video for pre-class assignments (*28*, *34*, *38*, *41–47*). Other instructors have students read their books (*31*, *33*, *39*, *40*). Some instructors, like Houseknecht and Goss (this book), combine both approaches (*48*).

Volume 1 of this collection starts by demonstrating how faculty members generate buy-in for novel pedagogical methods. Swearingen describes how she flipped the syllabus in her general chemistry course at John Brown University, introducing students to the novel approach and generating buy-in among students for the method. Next, the reader is introduced to logistics of implementing the flipped classroom. Storer describes his implementation of the flipped classroom

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in a general chemistry course at a community college in rural Ohio. An important characteristic of this course is that it served as a dual enrollment course for high school students in the region, many of whom did not have Internet access in their homes. His creative approach demonstrates logistics that make flipping possible even in challenging circumstances.

The next few chapters describe different methods used in flipped courses, transitioning into the educational theory behind the flipped course. Although most flipping of chemistry courses happens in general chemistry, the following two chapters both focus on physical chemistry courses. Goss describes the use of Just-in-Time Teaching combined with screencast videos that demonstrate the use of a symbolic math program like Mathematica to flip her physical chemistry courses at Idaho State University. Hagen describes the use of team-based learning (TBL) to flip his thermodynamics course.

Morsch's organic chemistry course is atypical, as each student is required to bring his or her own iPad to participate in the course. Morsch's students access pre-class videos on iTunes U and read assigned text on the ChemWiki. Students use a variety of apps on their iPad devices to respond to questions that Morsch poses. Morsch introduces the cognitive load theory to explain and interpret enhanced grades and student responses to surveys about the teaching method.

Lekhi's general chemistry students at the University of British Columbia are being challenged to develop skills that will enable them to productively participate in research projects. She explains how the flipped classroom promotes in these students a more sophisticated epistemology as they develop these research-ready process skills.

Of the chemists who are aware of the flipped classroom, many believe that the approach can only work in small classes. Several authors in this collection (Stoltzfus, Link, Soult, and Yestrebsky) dispel that notion, describing their successful implementations in courses that have over two hundred students. Stoltzfus teaches general chemistry at The Ohio State University. Link teaches organic chemistry at University of California, Irvine. Soult teaches general-organic-biochemistry for nurses at the University of Kentucky. Yestrebsky teaches general chemistry at University of Central Florida. Yestrebsky presents data demonstrating that average students benefit from the flipped teaching, with larger percentages of A's and B's in the flipped course than in a matched lecture course.

The chapters in Volume 2 of this collection provide further data about how flipping influenced their students' learning. Most authors found enhanced learning (Yestrebsky, Casadonte, Haak, Read, Houseknecht, Esson, and Muth); one reports similar grades (Maloney) in a course that previously included significant amounts of active learning. Casadonte flipped his honors general chemistry course at Texas Tech University. Haak describes a hybrid course with reduced face-to-face time for a general chemistry course at Oregon State University. Read describes partial flipping at University of Southampton. Houseknecht implemented Just-in-Time Teaching in organic chemistry at Wittenberg University, having students generate iPad screencasts in groups. Maloney teaches organic chemistry courses for classes of biology majors with up to 100 students. Esson flipped both general and

analytical chemistry at Otterbein University. Finally, Muth describes his flipped biochemistry course at St. Olaf College.

We hope this collection provides a starting point for faculty members to begin to reflect on practices in their own classrooms. Perhaps some instructors will be inspired to begin scholarly projects to understand how these methods influence learning in their classrooms. Even among the works provided, the need for further research in courses that employ some variant of flipped pedagogy in chemical education is warranted. Although comprehensive chemical education research may appear daunting, tools such as other symposium series (*49*, *50*) and collaboration with colleagues in the university education departments will be able to provide a deeper, more encompassing picture of the cognitive and affective benefits to this pedagogy.

The call for and relevance of larger reform efforts in chemical education is not new and has been part of an earlier symposium series (*51*). In sum, this series is a continuation in the possibities in achieving reform and meeting the goals of improving students' knowledge of chemistry.

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Chapter 2

Flipping the Syllabus: Using the First Day of Class To Encourage Student Acceptance of a New Pedagogical Technique

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Flipping is an educational technique that is growing in popularity. Because flipping is a relatively new concept, it is likely to be foreign to students, who may view the practice as increasing their workload in comparison to traditional approaches. Securing student acceptance and enthusiasm is crucial to successfully flipping a course and can be achieved by flipping the syllabus. Rather than describing the syllabus during class time, students watch a video explanation outside of class. The important first day is then freed up for participation in activities which help to build the foundation for classroom practices and emphasize the importance of the shared classroom community. In addition, flipping the syllabus allows students to investigate a new technique with a low stakes assignment. Students discovered through the assignment and discussion that flipping allows for videos to be re-watched at any time and place, allows for class time to be used for more engaging activities, and primes them with necessary information for class discussion. From a learning perspective, students discovering these benefits on their own before the addition of any complicated chemistry material is invaluable.

Introduction

Experimenting with flipping, like any new pedagogical technique, can be overwhelming, particularly if there is little external impetus to instigate reforms.

Significant course changes are undeniably hard and can require a substantial investment of time. However, studies increasingly show flipping to be worth the effort for our students. The purpose of this chapter is to demonstrate the importance aligning the first day of class with semester goals and to describe an innovative approach to introducing flipping in a course in order to promote student acceptance: flipping the syllabus. The present chapter will describe this approach using a combination of literature review, personal narrative, and student data.

Pedagogical Change

A chapter by Daus and Rigby in the ACS Symposium Series book, *The Promise of Chemical Education: Addressing our Students' Needs*, outlines tips for teachers desiring to make pedagogical changes. They offer five pieces of advice for their readers: 1) choose a pedagogy that reflects who you are, 2) start with small changes to see what works, 3) communicate your plans with students, 4) ask your students for feedback, and 5) be reflective about your experiences (*1*). Two years ago, I made the decision to flip my introductory chemistry course, and the only piece of their advice that I missed was number two. (For the record, I do not recommend eliminating this one.)

I had heard only a single presentation on the relatively new technique of flipping at the 2012 Biennial Conference on Chemical Education before I made the decision to flip. I will readily admit that my decision to flip my General Chemistry I course was made with slight naivety. However, I sensed immediately that it was the right decision for me and for my students, and this frequently encouraged me as I was slogging through multiple video takes and re-planning class periods.

When contemplating a new teaching approach, several barriers will surface. The time commitment is the most obvious one. Christiansen noted a 2.4-fold increase in prep time when flipping, and I found this to be accurate (*2*). Leaving behind a comfortable style is likewise difficult. In addition, I also recognized that flipping would almost certainly be foreign to my heavily freshman-populated course. Devising a plan for securing student buy-in would be crucial and would need to begin on the first day of class.

The First Day of Class

When I was a new professor at a teaching intensive university fresh from a postdoctoral research position, I thought little about the first day of class. Armed with a fairly standard checklist, I would take roll, present my credentials to students (which seemed especially important for a youngish female chemistry professor), read the syllabus essentially word for word, and dismiss. It made for quick work, and students weren't disappointed, likely because their own expectations for that first day were even lower than mine.

I'm not sure when or exactly how this changed, but over the course of a decade of teaching I began to appreciate that first day of class as not merely perfunctory but crucial in my pursuit of connecting with my students. That initial encounter

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with students, especially in introductory courses, sets the tone for the rest of the semester.

On that first day, both students and professors begin to form classroom practices that will define the norms, patterns, expectations, and behaviors of their shared journey through the course (*3*). Whether recognized or not, a student will enter your course with a myriad of questions: *Will this course be primarily lecture, or will I be expected to participate in some way in each class period? Do I need to come prepared for class in order to participate fully or will the professor give me the necessary information? Will I perform primarily as an individual or will collaboration and group work be promoted? Is asking questions encouraged or discouraged?* As much as possible, the professor needs to begin to answer these questions by aligning the first day activities with their design for the rest of the semester. In my case, I realized that having students listen to me exclusively present information was incompatible with my desire for them to be active participants in class. As Gafney and Whitaker argue, "simply reading the syllabus on the first day promotes a hidden message that students are expected to learn by listening" (*4*).

A significant classroom discipline to promote on the first day is the importance of class time. Nobody, especially students, wants time to be wasted. When students and professor meet together, activities should take place that are much harder, if not impossible, to replicate outside of class. Interaction between students and professor, working together on shared problems, and watching demonstrations of chemical principles are just a few examples. It probably goes without saying, but dismissing class early severely diminishes the value of these activities. Moreover, the professor should put some thought into activities that students will perceive as intriguing—dare I say it, even fun (*5*). Of course this is not the primary goal of any class period, even the first day, but learning will only be enhanced if students are engaged.

Aside from shaping classroom norms, the first day of class forms students' impressions of their professor. Beyond their questions about the course, students want to know about the authority figure standing before them. We frequently hear that first impressions matter, and the classroom setting is no different. In fact, in a fascinating book called *The Tell*, Matthew Hertenstein summarizes a series of experiments revealing that observers could accurately predict end of semester course evaluations simply by watching footage of the first day of class. In fact, it only took six seconds of video to make these accurate projections (*6*). Wilson and Wilson manipulated the first day of class to be either a positive or negative experience for students and found not only higher course ratings and but also perceived effectiveness of the professor in the positive condition. In addition, these students achieved higher course grades when compared to the negative group (*7*). Student motivation appears to play a role in this and other studies, and the authors conclude that professors should consider using the first day to "ease students' minds rather than fill them" (*7*, *8*).

In my own case, I teach an introductory chemistry course, largely populated by traditional freshmen majoring in science and engineering. Reflecting on my students over the years, I began to recognize that I needed my students to walk away with two crucial pieces of information after that initial class period: first,

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that my greatest desire is to see them all succeed, and, second, that I am not to be feared. Clearly, standing up in front of class, regaling them with my credentials and lecturing them on the syllabus was not going to get the job done. In addition, the pedagogical technique of flipping needed to make its appearance in order to begin the process of promoting student acceptance.

Flipping General Chemistry I

Flipping the classroom, popularized by Jonathan Bergmann and Aaron Sams in their book, *Flip Your Classroom: Reach Every Student in Every Class Every Day*, reverses the typical lecture and homework routine (*9*). Traditionally, information in the form of lecture is delivered during class time, and then students practice applying principles outside of class. Bergmann and Sams noted, however, that students are often most in need of professor feedback while wrestling with homework problems. This was certainly true of undergraduates in my General Chemistry I course, where I heard from students on a fairly regular basis, "I understood the lecture, but then I couldn't do any of the homework problems," too often followed by "I gave up trying." While the exact approach to flipping the classroom is variable, it often involves creating video lectures, which students watch as out-of-class assignments. As a consequence, class time can be repurposed to work problems and other active learning pursuits while the professor is present to assist.

Though flipping is relatively new, data assessing the impact of flipping on student performance is beginning to accumulate. Recent studies have supported higher learning gains in the flipped versus the traditional classroom; in fact, increased scores have been observed on ACS exams, instructor-created tests, and online homework sets (*10–12*). Lower DFW rates have also been noted (*13*). An important benefit, especially in STEM fields, is the data showing that gains achieved in a flipped environment are more significant for women and students with lower GPAs (*12*, *13*). Reasons for the improvements likely include the ability to watch and re-watch videos at different paces, employment of more active learning activities during class, increased practice problems for any given topic, and strengthened interactions between other students and with the professor (*14*).

My General Chemistry I is a fall course of roughly eighty students, divided into two sections, and largely populated by freshmen science and engineering majors. In the fall 2013 and fall 2014 semesters, the class was half-flipped. In fall 2013, half of the textbook chapters were flipped while the others were traditional lecture. In fall 2014, the delivery format was reversed, i.e. chapters that were traditional lecture the previous fall were flipped and the flipped chapters reverted to traditional lecture. I created all videos using an interactive pen display for annotating the slides, recorded audio utilizing lecture capture software, and uploaded videos to our learning management system for student use. Videos were kept short, generally less than ten minutes, and only covered one or two major concepts.

Expectation of student preparation is key in a flipped classroom. If a student does not watch the video before coming to class they will be lost and frustrated.

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When discussing material in a chapter that was being flipped, students were not only expected to watch the videos, they were required to take notes, just as they would be if physically sitting in the classroom. In an effort to hold students accountable for the pre-class work, I employed a number of different credit-bearing assessments, including answering a short quiz using notes, writing down the muddiest point from the video, or simply assigning points for notes. In addition, because the videos were posted on our learning management system, video usage was automatically tracked for every student.

When delivery of information is moved outside of class time, the schedule opens up for more active and engaging practices. After the assessment to persuade students to watch the videos was completed, students were encouraged to ask questions raised by the video. If pertinent, I performed chemical demonstrations to illustrate principles for the day, often with the help of student volunteers. The majority of time was spent in small groups working through clicker questions, designed to apply principles from the video and address common misconceptions. As students worked together, I circulated through the room answering questions and occasionally stopping the class to deliver a just-in-time mini-lecture.

Delivery methods were varied over the two fall semesters in order to collect data for an unpublished study. Briefly, the presentation of material alternated between traditional lecture and flipped. Scores on individual test items were analyzed to determine if there was any difference in performance between the two formats. Though more data is needed to draw firm conclusions, students achieved higher scores when the material was flipped in one semester and had fairly comparable scores in the second semester.

Setting the Stage: Flipping the Syllabus

So how does one go about introducing flipping, particularly on the first day? It is imperative that the first day of class activities help build the foundation for standard classroom practices, emphasize the importance of shared class time, and align with the expectations for the rest of the semester. In addition, it is important to remember the two impressions I wanted students to leave with—that my desire is for them to be successful and that I am not to be feared.

Instead of business-as-usual on the first day, I planned a series of activities designed to engage students, help them meet and become comfortable with me as well as their peers, and encourage asking questions and voicing fears. The homework assignment and subsequent discussion on the second day introduced the students to the concept of flipping.

Beginning the first day of class by calling roll may sound uninspiring, but it can be an opportunity to begin learning names and building rapport. As I voice student names, I make eye contact with each of them as I drift around the classroom. Asking questions is an important part of this process, and I inquire about correct pronunciations of names, origins of names, nicknames, hometowns, etc. Next, a couple of ice breakers help students gain familiarity and begin to get comfortable with each other. The final activity, which takes the most time, consists of randomly grouping students. One student in each group logs onto a

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backchannel website and posts an element as their group name. (There are many of these backchannel web tools available free of charge that automatically create transcripts for future use.) Each group then answers the following three questions.

(1) What burning question do you have about this class?
(2) What are you most nervous about?
(3) What questions would you like to ask the professor?

After each question, I read the group posts out loud and comment on each of them. When appropriate, I utilize humor in my answer. Inevitably, one question that students ask is, "Where is the syllabus?" At the end of class, I assign the homework—to watch a video about the syllabus that is posted on the learning management system and come prepared to use that information when we meet again. The syllabus video features a ten minute narration over the written syllabus. The lecture capture software that is integrated with our learning management system has a user-friendly interface where students can easily play, rewind, or fast forward through a video. A paper copy of the syllabus is provided for students who want it on the next day of class.

The second day of class begins with the groups reforming and utilizing the same backchannel website to answer questions about the homework. When asked what they liked about watching a video explanation on the syllabus as opposed to discussing in class, students said that it "incorporated different individual's learning methods" and also noted that "it gives you the ability to re-watch parts." Importantly, they also picked up on the fact that watching the video outside of class "saved class time," "gave extra time in class without having to go over the syllabus," and allowed the professor to "utilize class time for other things."

Reflection about what students did not like was instructive as well. The most commonly cited answer was issues with technology. Groups also recorded that it was "easier to disengage, multitask, and miss bits" and admitted that it was "easy to get distracted." Four groups posted the same answer, saying that they missed being able to ask questions while watching the video. One group humorously, but honestly, posted that they didn't like the video simply because "it was homework."

The question I was really interested in was the last one, "Why did the professor assign the syllabus as a video?" Several of the groups guessed that my agenda was to get them familiar with the learning management system and video capture. They also recognized that posting a lecture would allow them to return to the video if they had questions during the semester. Realization that students were expected to come prepared for class time was noted, and one group astutely wrote that, "We are now engaged in active discussion on your desired topic." Two groups said that it "saved class time" and "watching a video lecture outside of class, then doing work in class [is] more helpful." Teasing this idea out further in discussion, students noted the fact that if we had gone over the syllabus in class, the consequence would have been a loss of one, possibly two, activities that could not have been replicated online.

Only after collecting and discussing the answers to these three questions do I name the educational technique of flipping in class. By flipping the syllabus, students discovered the advantages of flipping by themselves through

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self-reflection and class discussion. They were also able to get comfortable with the technology with a low stakes activity. Most importantly for my purposes, they saw a vital benefit of flipping is richer, more fruitful class time. In short, they sensed that it was worth the effort.

Conclusions

Flipping the classroom is a pedagogical technique which has increased in popularity as studies amass, validating its effectiveness in achieving student learning outcomes in chemistry courses. Because flipping will be an unknown method to most students, it is essential that the instructor give careful thought to how the topic will be introduced so that student acceptance is maximized. In my introductory chemistry class, this was achieved by flipping the syllabus. The first day activities were designed to promote other professor-driven goals of connecting with students and making them feel comfortable. When flipping chemistry material began over the next few weeks, students already understood not only how to use the technology but also recognized the benefits of flipping, both inside and outside of the classroom. For the professor new to flipping, an additional personal benefit is a low stress introduction to the technique.

The first day of class is important, and those initial impressions have been shown to yield results throughout the semester. A probable assumption is that students are buying into the course and are motivated to do well. A future study could investigate the relationship of student appreciation of flipping after this introductory activity and individual test scores or course grades.

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Chapter 3

The Flipped Classroom with Limited Internet Access

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Flipped classes move the lecture content outside of the classroom, typically online, and allow for a more active learning environment in which students have the opportunity to engage more extensively with both the instructor and other students. In rural areas where internet access is limited or prohibitively expensive, an alternative is necessary to provide lecture content. A model is described here that provides the students with three avenues for obtaining video lecture lessons. A key component is an e-learning software tool that allows the packaging of lessons that can be viewed in a browser without internet access. Also described is how the development of a flipped general chemistry curriculum made possible the implementation of a dual credit chemistry course in rural high schools.

Introduction

Located at the foothills of the Appalachian Mountains in rural southern Ohio, about an hour east of Cincinnati, Southern State Community College (SSCC) serves a sparsely populated region that includes some of the poorest counties in the state. As such, internet access and cell phone coverage can be limited and high speed internet access using a satellite dish can be expensive. This environment creates some unique challenges for delivering high quality college courses that allow students to compete for scholarship dollars and entry into pre-professional programs when transferring to the four-year universities. Since the founding of SSCC in the mid 1970's, the state has added a campus in 4 of the 5 counties of the original service area to make the college accessible and avoid excessive

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driving times for students. Each of the four campuses has laboratory facilities for teaching chemistry in an integrated laboratory/lecture format. To minimize commuting expenses for students, many classes only meet two days per week but use an extended class time to meet requirements for instructional minutes.

Dual Credit Chemistry

Initiation of the flipped classroom began with the development of a dual credit chemistry program which was funded by a grant from a local educational service center. To keep the process simple, SSCC began by offering introductory level chemistry for dual credit. The reasoning for this decision was that the introductory level chemistry was essentially the same level as the high school chemistry courses in terms of credentials of the instructors, laboratory facilities, etc. The purpose of the grant was to implement college-level chemistry, so we began the development of a model to implement a dual credit, college-level chemistry course. A high school that was physically close to one of SSCC's campuses was chosen for the pilot. Because the high school teacher was not credentialed to teach at the college level, I recorded video lectures that were typically 30-40 minutes in length which were posted on my college website. The students met with the high school teacher and performed mini-labs as an introduction to the topic, worked problem sets, and received clarification on topics with which they were struggling. Although this was not the original intent, in some instances, due to problems with internet access, the students watched the recorded lectures during the face-to-face meetings with the high school teacher. The students drove to the college campus each week to complete the laboratory instruction, which was taught with help from the high school teacher. That first year was considered a success; informal follow-up conversations with students after they moved on to universities indicated that they were well prepared in general chemistry. However, this model was not replicable because not all high schools in the area were as close to a campus. From this pilot I learned the following:

- Keep online lectures short. The students reported at the end of the course that the online lectures were too long, and frankly, boring. To save time, a video camera to record lectures when conducting traditional face-to-face classes was attempted, but, based upon the feedback from students, it became apparent that this was not an effective alternative. Upon further study of best practices for online courses, it was learned that online lessons should be no longer than about ten minutes (*1*). Philip Guo, an assistant professor of Computer Science at the University of Rochester studied student engagement as related to video length and recommends that length not exceed six minutes (*2*). Lessons should be interactive, not simply a video to be watched.
- Find an alternative for students without internet access. Some, if not most of the students were watching the online lectures at the high school with their high school teacher, which was not the intended delivery mode. A delivery technique that was not internet dependent was needed.

- Create a way for students to do college-level labs at the high school.

The Flipped Classroom

The development of the video lectures for an entire general chemistry course encouraged me to use these resources somehow in my traditional face-to-face classes. These original video lectures were a good starting point to begin flipping my classes, but my only method for distributing the lectures was by posting them on my website. I quickly realized that if students were to be held accountable for the at-home lessons, alternative delivery methods would need to be implemented. In addition, some method for making the video lessons interactive was needed as well. The answer to this problem was the e-learning authoring tool, SoftChalk (*3*), which is a software package that allows for the creation of application files that run in a browser without the need for Internet access. It is an extremely easy to use tool that is very similar to word processing software and allows for the insertion of videos and interactive questions in a lesson that can be used in a variety of formats. Students have three ways to access the course materials:

- Using SoftChalk the lesson can be packaged and copied to a USB flash drive that students can use on their computers without having Internet access.
- For students who have Internet access, the lessons are also posted on the college learning management system, Blackboard.
- For students with smart phones, the video lecture portion of the lessons are accessible via QR codes placed in the margin of class handouts and a free app (TapMedia for iPhone (*4*), or Android (*5*)) on their phone will allow them to watch the videos. The QR code simply encodes the URL which leads to the video. The disadvantage of this technique is that the interactive questions are not part of the videos. (See Figure 1.)

Figure 1. A QR code allows students to watch video lessons on their cell phones.

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The advantage of the QR codes is that the video files are a different file format, so some technical problems the students have in accessing the video lectures may be eliminated by using this alternative.

Creating Video Lectures

As mentioned earlier, it is important to create short videos that will hopefully engage the students' interest in the topic and made in such a manner that will not become quickly dated and need to be redone frequently. Having the instructor appear in the video can quickly date the video due to changes in clothing, glasses, and hairstyles. In chemistry video lectures, we want a method to present conceptual content in a logical fashion and a method to show students how to work problems, balance equations, etc. I used three types of software to create the video lectures: (1) For my face-to-face classes, I had previously created PowerPoint lectures with embedded animations and videos, so I used those as the overall organizing structure for the lessons. (2) To take the place of working problems on the board, I utilized OneNote which is a software program that allows for handwritten notes and is part of Microsoft® Office (*6*). This program was used on a tablet computer which would allow one to write directly on the screen using a stylus. (3) A screen capture program will, as the name implies, capture whatever appears on the screen of the computer and capture the audio from a microphone or audio from an on-screen video. It will then create a video of the information captured in a variety of formats. Although there are free or inexpensive screen capture programs from Techsmith® (*7*), such as Jing or Snagit, I chose to use Camtasia because of the editing capabilities available in the program. For example, the program has a timeline of the recorded video that will allow the removal of unwanted background noise or portions of the recording that did not turn out as expected. During the editing process, Camtasia also allows the user to insert callouts which can be arrows that point to a particular point on the screen, highlighting text on a slide, or a textbox that pops up with additional information. During the final production of the video, Camtasia allows for the exporting of the video in a variety of video file types. To create short videos, one needs to rethink the presentation of a topic. For example, rather than make a video lecture on intermolecular forces as a whole, individual videos on each type of intermolecular force such as dipole-dipole, hydrogen bonds, etc., could be made. This effective technique is referred to as "chunking (*8*)." Another enhancement one can make is the creation of embedded video problems. Students frequently complain about not understanding a problem in a text because they cannot visualize the reaction or process that is relative to the problem. By embedding a video of the particular reaction or process, the student may better be able to work the problem. The QR code in Figure 1 leads to an embedded video problem of density by water displacement and shows a metal being added to water in a graduated cylinder. All of the data presented in the problem is visible in the measurements being made in the video.

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Incorporating Video Lectures into an Interactive Lesson

Although this author does not utilize all of these features in SoftChalk it is possible to create interactive lessons (a) which can be posted to a learning management system (LMS) that have assessments that can be tallied in the LMS, (b) with accessibility features, and (c) as part of an eBook builder. Probably most importantly, however, is the ability to make video lectures interactive. As was mentioned earlier, SoftChalk appears much like word processing software. The interface is shown in Figure 2.

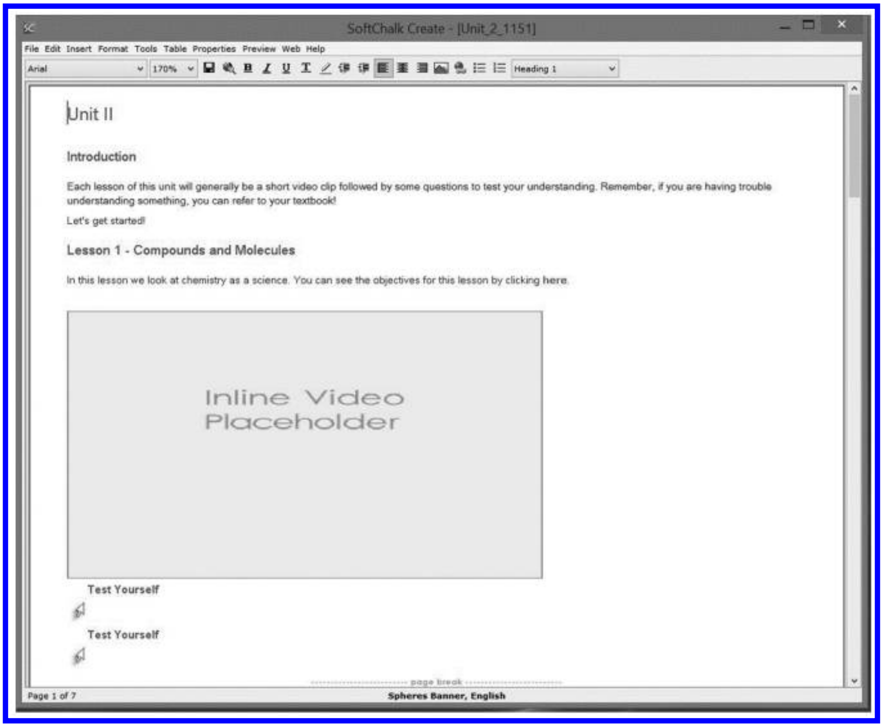

Figure 2. SoftChalk lesson creation. (SoftChalk images reproduced with permission from reference (3). Copyright 2014 SoftChalk.)

Interactive features of this lesson are: (1) there is a dropdown menu of all lessons in the unit, (2) the objectives for the lesson can be accessed by clicking on a link, (3) the video can then be watched, and (4) the "Test Yourself" questions that immediately follow the video. The finished product is shown in Figure 3.

This lesson can be uploaded to an LMS if internet is available, but it can also be packaged as an applicaton and copied to a USB flash drive and used in a browser without the need for internet access.

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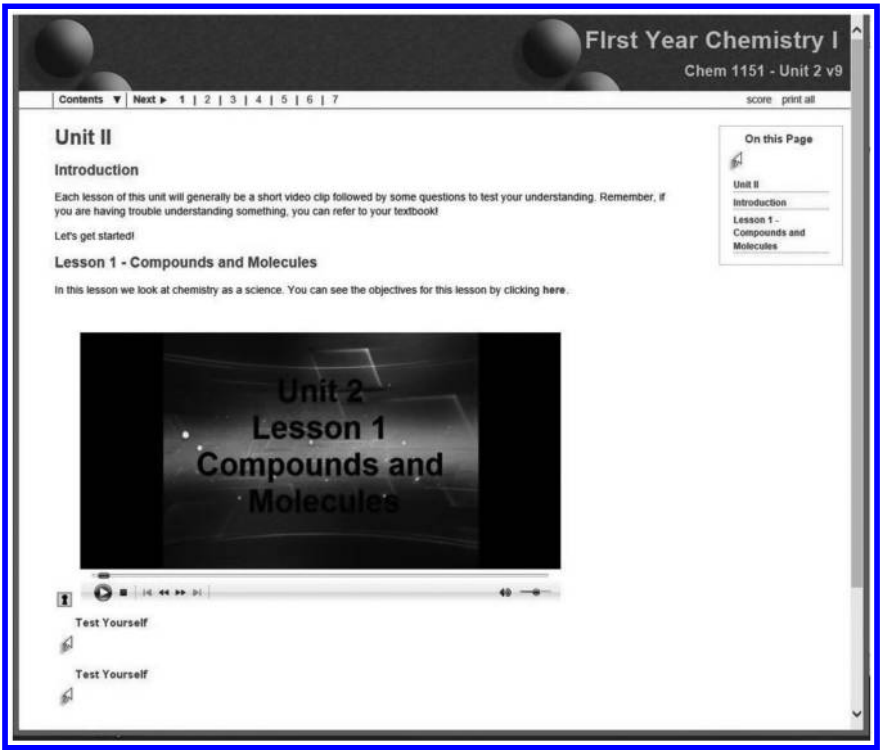

Figure 3. View of finished lesson. (SoftChalk images reproduced with permission from reference (3). Copyright 2014 SoftChalk.)

Creating QR Codes

Some students may have a smart phone but an old, outdated computer. The QR codes allow those students to access the video files which were used to create the interactive lessons in SoftChalk. As mentioned earlier, the interactivity is lost, but at least the students can access the lectures. For example, a student of mine whose son was in the hospital for an extended stay was able to access the videos on her phone while staying at the hospital. The QR codes can be distributed to students in a variety of ways, but I paste them in the margins of the PowerPoint handouts next to the beginning slide in the video.

To create the QR codes, any URL can be used, but in the example described here, the videos must first be uploaded to YouTube. Because I use ancillary materials such as animations and videos provided by the textbook publisher, I was concerned about copyright issues. So that only my students can view the videos, I learned that one can set the privacy setting to “Unlisted” in YouTube so that others can’t access the video. Once the videos are uploaded to YouTube, a URL is created for that particular video which can be copied and pasted into a free QR code generator program that is available online (*9*). Once the QR code is created, because it is just a picture file, it can be copied and pasted into any document. It

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is advisable to caption the QR code with a descriptor so that it will be obvious what video it represents.

One Strategy for Flipping a Chemistry Classroom

If one searches the internet for "Flipped Classroom" there are many articles and blogs related to flipping classes and the methods various instructors have devised to make use of the face-to-face time with the students. One study published in 2015 which attempted to address the research associated with flipped classes in higher education, found in excess of 1000 research articles, but only 28 met the requirements for their study relative to higher education (*10*). There are a variety of strategies on how to best flip a class and no one strategy will work in all classroom settings. Bergmann and Sams (*1*) describe a sequence that involves assigning the at-home video lesson for their high school classes. The next day, class begins with a question and answer session, followed by in-class problem sets. On lab days, the flipped model allows more time for help with lab calculations. They recommend making videos that have a picture-in-picture of the presenter and choose to do a team presentation. Ryan and Reid (*11*) assigned their students in general chemistry three videos per week coupled with a publisher homework system. At SSCC, we have the luxury of having the schedule and facilities to allow for integrated lecture and laboratory. An integrated lecture-laboratory environment for large general chemistry classes was described by Bailey and coworkers at California Polytechnic State University (*12*). One question I am asked frequently by instructors who have not tried flipped classes is "What do you do about students who do not do the at-home lessons?" My response is usually something to the effect that the result is the same anytime students don't do their part; they perform poorly in the course. To drive this point home, I frequently remind the students that basketball players cannot get into playing condition by watching the coach run laps around the gymnasium.

The following are the components of my flipped classroom:

- Take-home quizzes – To encourage students to do "their part" to engage in the interactive lessons, take-home quizzes of 10-20 questions are given over each unit. Many of the questions can only be answered by watching the video lessons.
- Mini-labs – Each unit includes a hands-on activity to introduce the students to some concrete observations of phenomena related to the concepts to be presented in the lessons. For example, the unit on equilibrium is introduced with a microscale lab activity using the traditional cobalt chloride complex equilibrium. The mini-labs do not replace traditional experiments that make up the laboratory component of the course; they are merely part of the "lecture" block of the course.
- Lecture - Just because students have most of the lecture material covered online, it does not mean that they would not benefit from an explanation of some of the more complex topics. The high school teacher moderates these sessions. This allows for the exchange of ideas and questions

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that are only possible in a face-to-face environment. If the teacher has difficulty with any of the topics, he or she always has the professor as a resource by phone, email, or live video lecture.

- Student Response Systems (Clickers) – Shortly before the unit exam, students are formatively assessed using clicker questions which are mapped to similar questions on the exam. This technique allows both the students and the instructor to assess their understanding of the concepts. For problem solving, an in-class problem set is used which allows students to get help as they are working the problems.

Flipped Classes in the Dual Credit Classroom

This chapter began with a description of how dual credit classes at SSCC led to the development of a system for flipping classes. That process has come full circle and has led to a unique model for implementing dual credit, *college-level general chemistry* classes in high schools which are not physically close to a college campus. Recently, Ohio implemented a new law called College Credit Plus (*13*) which updates the requirements for dual credit classes and mandates that the high schools work with colleges to offer dual credit classes. Two major obstacles to offering college-level chemistry classes are that, at least in the SSCC service area, (1) the majority of high school teachers are not credentialed to teach at the college level, and (2) there is insufficient equipment in some schools to complete college-level experiments. This model is in the second year of implementation and places the high school teacher in a similar role to the teaching assistant (TA) at a university.

The structure for this model is as follows:

- The lecture consists of the lessons outlined above and delivered as described, either online or via USB flash drives. The professor visits each high school so that the students get to know the instructor they are hearing on the lesson. At the time of this writing, there are four high schools participating, with the farthest high school being a 2-hour drive from campus.
- All tests, quizzes, mini-labs, experiments, and handouts are the same ones used on campus by the professor.
- The course pace and sequence is also the same as used by the on-campus students. The high schools agree to modify the class schedule to allow for the classes to be offered. In some cases, the labs occur at the end of school and students stay after to complete the labs. In other cases, we have been able to creatively split a lab over two days.
- The college loans the necessary equipment to upgrade the high school lab so that college-level experiments can be performed. Because these are small classes (averaging 7 students per section), a large amount of equipment is not necessary. The plan is that as the high schools build their equipment inventory, this loaned equipment can be returned to the college to be loaned to other schools as the program grows. Some labs,

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such as those involving pH meters and spectrophotometers are purposely scheduled at the college so that students also have the opportunity to be on campus. The high school that is 2 hours away from campus has more limited opportunites to visit campus. The plan for next year is to implement a more creative approach by scheduling the class at a later time to allow for more visits by the professor, and/or increase the use of live video broadcasts over the internet.

- All teachers attend a 2-day workshop in the summer and a 1-day workshop at the end of the fall semester. They receive a notebook of lecture notes, problem sets, and quizzes, as well as a USB flash drive with all files and lessons. They complete the experiments that are deemed to be most troublesome. These workshops also allow the teachers to trade ideas on how to best implement this college-level course in their schools.

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What we have learned:

- The workshops allow the professor and teachers to get to know each other, which has led to a constant exchange of ideas. It also seems to break down barriers that would inhibit the teacher from asking for help. There is almost daily communication among the teachers and the professor.
- The professor needs to understand the pressures and restraints under which the high school teachers are working. One example: the internet is severely restricted at many high schools, so an online resource may not be accessible to the class while they are in school.
- The students have expressed that they enjoy the lessons and content, but, at the same time the scope of the course has been a total shock to many. Some students have gotten a bad grade on a test for the first time in their lives. In one case, the professor and the dual credit coordinator visited the school to reassure the students and make them aware that we all suffered a similar shock when beginning college. Learning how to handle challenges of a difficult class while the students are in the comfort of their home environment should be extremely helpful as they transition to a university environment.
- To be successful, this model requires an extreme level of organization on the part of the professor and the high school teachers.

Frequently Asked Questions

The following are frequently asked questions and my responses as a flipped class instructor:

- Do students learn more in the flipped classroom versus the traditional lecture?

  As with any new methodology such as flipping classes, the instructor may *feel* that *increased learning* has occurred, but that can only be proven with a research project to determine, if indeed, there

has been any increase in knowledge of the subject. Some recent studies have found improvements. Ryan and Reid found in a parallel controlled study in general chemistry that only the bottom third of the flipped class was significantly better than the traditional section (*11*). Students in a flipped general chemistry study by Weaver and Sturtevant performed significantly higher than the traditional approach (*14*). Other recent studies report similar results, as well (*15–18*). A related potential enhancement, however, is the student's attitude toward the subject and if he or she remains in a STEM (Science, Technology, Engineering, and Math) field of study. Students involved in Weaver and Sturtevant's study (*14*) responded favorably to the flipped format and grew more positive as the in-class activities were improved from year to year. Ryan and Reid's study (*11*) as well as other researchers, have reported positive attitudes toward the flipped format (*19*, *20*). My enthusiasm for the method is the *increased availability* of content. My students frequently remark about how useful it is to have the ability to "replay" an explanation of a topic as many times as necessary to achieve understanding. One student relayed to me that her young daughter would sit at the computer and watch my chemistry lectures!

- Won't the students stop attending class?

    I have observed absolutely no decrease in attendance. Students will attend class, and this is the challenge for the flipped class instructor, if there is perceived value in attending. If useful learning activities are provided, students will attend class. For non-traditional students who are attempting to balance work and family life with school, having all of the online lectures available is especially helpful when missing class is unavoidable.

- Do you use any online homework supplemental resource in your classes?

    I do not because of the take-home quizzes, problem sets, and laboratory activities that I have already created. The disadvantage of that is, of course, the amount work necessary to create those resources. An advantage, however, is that, if appropriately designed, the lessons can be independent of textbook changes or re-sequenced to the preference of the instructor.

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Chapter 4

The Use of Active Learning and a Symbolic Math Program in a Flipped Physical Chemistry Course

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This chapter describes the author's experiences in converting the physical chemistry two-semester course sequence to a flipped format to free up class time for the use of cooperative learning. Lecture material was moved to screencast videos and a Just-in-Time-Teaching framework was used to organize before-class and in-class activities. The overall structure of the course is described. Class sizes have been too small to quantitatively show improvements in student outcomes. Survey responses suggest that students believe the techniques used in the author's flipped classroom help them to learn physical chemistry. Responses also suggest that students believe use of a symbolic math program leads to better conceptual understanding. Insight has been gained into both when and why students struggle with physical chemistry. Screencasts have been found to be effective for helping students learn to use a symbolic math program such as Mathematica.

Introduction

There are a small number of studies investigating factors correlated with student success in physical chemistry courses. Nicoll and Francisco (*1*) found that math ability as measured by a written questionnaire was an important factor but the best predictor of student success in physical chemistry was logical thinking skills as measured by a conceptual diagnostic instrument. Derrick and Derrick (*2*) found strong correlations between success in physical chemistry and such

factors as grade in second semester calculus course, grade in second semester organic course, and grade in second semester general physics course, but not with grades in other chemistry courses required for the major. Hahn and Polik (*3*) found correlations between success in physical chemistry and the average general chemistry grade, the average grade in all math courses, and the number of math courses taken. They also found a correlation between physical chemistry homework scores, which may correlate with study skills and motivation, and success in physical chemistry.

Both Nicoll and Franciso (*1*) and Sozbilir (*4*) investigated student and instructor perceptions of physical chemistry. Nicoll and Francisco (*1*) report that some students enter physical chemistry courses with negative perceptions and low expectations for personal success. Sozbilir (*4*) reported that both students and instructors perceive the abstract concepts of physical chemistry and courses overloaded in terms of content to be major problems affecting student learning in physical chemistry.

The topics which belong in physical chemistry courses has been the subject of scrutiny. *Physical Chemistry: Developing a Dynamic Curriculum* edited by Moore and Schwenz (*5*) focused on curriculum issues. Zielinkski and Schwenz (*6*) reviewed the physical chemistry curriculum as well as related issues of teaching and learning and provided options and recommendations for change. The broader *Advances in Teaching Physical Chemistry* edited by Ellison and Schoolcraft (*7*) addresses the curriculum issue and also contains a chapter which provides an review of the chemistry education research specific to physical chemistry up to 2009 (*8*).

The research on the teaching and learning of certain parts of the physical chemistry curriculum has been reviewed in detail since the publication of *Advances in Teaching Physical Chemistry*. Bain and Towns reviewed the research on the teaching and learning of chemical kinetics (*9*) and classified the reported alternative student conceptions using the general chemistry concept map (*10*). Investigations of the effectiveness of instructional approaches indicate that the alternative approaches to instruction examined promote understanding of chemical kinetics concepts in ways that traditional instruction does not (*9*). Bain and Towns also indicate that students do not fully understand such fundamental math concepts as function, variable, differentiation, and rate (*9*). The literature on the teaching and learning of thermodynamics has also been reviewed (*11*). This review also examined student alternative conceptions in thermodynamics and discussed the factors affecting success in physical chemistry and the role of math in thermodynamics (*11*). The finding that students do not always use their mathematical knowledge in new settings led to a recommendation to assess prior math knowledge and scaffold students' learning to use math in new settings (*11*).

Mack and Towns reported a detailed investigation into faculty beliefs about purposes for teaching physical chemistry and find that the most common belief about the purpose was to "help students develop their knowledge of fundamental concepts" (*12*). Other beliefs discussed included the role of problem-solving, mathematical modeling, and communication and team skills (*12*). The current status of physical chemistry courses has recently been examined by Fox and Roehring (*13*). They found that instructors believe that students struggle in

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physical chemistry courses because students lack the necessary math background and also that students struggle to make connections between math and concepts (*13*).

Symbolic math programs have been used in physical chemistry courses since at least the beginning of the "Mathcad in the Chemistry Curriculum" column in the *Journal of Chemical Education* in 1998 (*14*). Instructional documents prepared in Mathcad were peer-reviewed and published in this column. The column was renamed "Symbolic Mathematics in Chemistry" in 2004, reflecting a broader scope (*15*) and the column continued in that form through 2009 (*16*). Zielinski discusses the arguments for the use of symbolic math programs like Mathcad, Maple, and Mathematica in physical chemistry, as well as elsewhere in the chemistry curriculum, in references 14 - 16 as well as other installments of the column (*14–16*).

The literature on the use of the flipped classroom in higher education chemistry courses has been reviewed by Seery (*17*). He concludes that educators adopt it as a means of incorporating active learning into their courses and to make time for deeper understanding of chemistry, among other reasons (*17*). The flipped classroom in chemistry was the subject of an online conference, described by Luker et al. (*18*), and one of the contributions (*19*) refers to a flipped second year thermo class in the UK system. The flipped approach seems to be more common in general, organic, and other lower division chemistry courses than in physical chemistry courses. This is consistent with Fox and Roehring's report that only 8 of 331 survey respondents use a student-centered approach in teaching physical chemistry (*13*).

Research on the flipped classroom approach to teaching indicates that the benefits of the flipped approach may not be due specifically to the use of videos as before-class work (*20*). The inclusion of active learning methods that is made possible when the introduction of material is moved from an in-class lecture to a before-class video is likely to be responsible for the gains observed (*20*).

Given the challenges of physical chemistry for both students and instructors and the potential benefits of the flipped classroom approach, the author converted the physical chemistry two-semester sequence to a flipped format starting in the fall semester of 2013. The purpose of this chapter is to share some of the details of the implementation of the flipped classroom in the author's physical chemistry courses in a way that may help others considering such a change. This chapter will address the specific motives for change, the pedagogical tools used to accomplish that change, the structure of the course, and the lessons learned in the process of that change. Throughout, "the instructor" refers only to the author.

Objectives for Change

One of the main driving forces for the changes the author has made in teaching physical chemistry over the years is the way students experience the class. Sozbilir found that students believe conceptual understanding is not promoted or assessed and they must simply memorize definitions, facts, and

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equations to succeed in physical chemistry (*4*). This is consistent with the author's impressions from conversations with students. Students may perceive physical chemistry as an applied math class where they solve problems but don't understand the underlying concepts. Improving the students' level of conceptual understanding is a major driving force for the changes the author made in the conversion to a flipped classroom.

Hadfield and Wieman reported a detailed investigation of the relationship between solving problems in thermodynamics and conceptual understanding of thermodynamics (*21*). They gave a multiple-choice survey and a written-response survey to 55 students who completed "Chemical Thermodynamics and Kinetics," a first semester physical chemistry course. Ten students were individually interviewed about their thinking as they answered the survey questions. The instructors of the course the students took thought that the students would "easily answer" these survey questions about heat, work, and the first law of thermodynamics based on the problems they worked during the class. After analyzing the surveys and interviews, however, the authors concluded that students who had been successful in the first semester of physical chemistry remained "unable to properly interpret the physical meaning" of three key thermodynamic equations (*21*). If solving problems does not reliably lead to conceptual understanding, then additional instructional methods are needed to promote conceptual understanding along with problem-solving skills.

Teaching students problem-solving skills that are useful both inside the physical chemistry course and outside the immediate context of the course is another objective for the author. This requires teaching both problem-solving skills and the use of modern tools to do problems that are not over-simplified or too abstract. The use of a symbolic math program for problems in physical chemistry may be beneficial (*6*). The author started incorporating a symbolic math program into physical chemistry courses ten years ago. Programs such as Mathematica (*22*), Maple (*23*), Sage (*24*), and Matlab (*25*) can easily perform the time-consuming math of certain types of problems in physical chemistry. In the author's experience, they do so at the cost of the time required to learn to use the program and at the cost of the time spent finding syntax errors and typos. Some students have experience with such programs from math classes and a few have experience with one or more programming languages but in the author's experience, a significant fraction of the students are completely new to such a program and have to learn the program at the same time that they are learning physical chemistry.

The author's motive for incorporating screencasting in particular into the flipped physical chemistry course was the challenge of teaching students to use a symbolic math program. Prior to converting to a flipped class, the author taught the use of a symbolic math program to an entire class of students in a computer lab outside class time. The author's laptop was connected to a projector in the computer lab to demonstrate commands and techniques. These on-screen demonstrations were alternated with checks of student work. This was effective in that the students learned the Mathematica they needed to know and could get the instructor's help, but this approach suffered from the range of different paces at which students work in a given class.

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The Case for Active Learning

A recent article in *Proceedings of the National Academy of Sciences* describes a meta-analysis of 225 studies investigating examination scores or failure rates in STEM courses (*26*). Courses taught with a traditional lecture approach were compared to courses taught with an active learning method. The results indicate that average examination scores improve and failure rates decrease in courses taught with active learning methods to a significant degree across all STEM disciplines. The authors assert that the evidence against traditional lecturing is so strong that it should no longer be used as a control in such studies (*26*). Commentary on the article by Nobel Laureate Carl Wieman is particularly pointed:

> "If a new antibiotic is being tested for effectiveness, its effectiveness at curing patients is compared with the best current antibiotics and not with treatment by bloodletting. However, in undergraduate STEM education, we have the curious situation that, although more effective teaching methods have been overwhelmingly demonstrated, most STEM courses are still taught by lectures—the pedagogical equivalent of bloodletting" (*27*).

The author's earliest attempts to incorporate cooperative learning into physical chemistry were hampered by the time constraints of introducing concepts in lecture and incorporating cooperative learning exercises into the same class period. This was a major driving force for the author's switch to the flipped approach.

Conversion to Flipped Classroom

At the Biennial Conference on Chemical Education in 2012, there were several talks about the "flipped" method of teaching (*28–31*). The flipped approach was immediately appealing to the author for physical chemistry for two main reasons. One of the author's reasons to switch to a flipped course was that it would allow nearly all of class time to be spent on cooperative learning by moving the lecture introduction of material out of class time and into screencast videos. The increased use of cooperative learning in physical chemistry was expected to benefit student learning. The author's second reason to switch to a flipped course was that the author expected it would be a better way to teach physical chemistry students to use a symbolic math program. Students would be able to alternate between watching a screencast video demonstrating the use of Mathematica and working on that material in their own Mathematica files.

Strategies for Incorporation of Active Learning

There are two main active learning strategies that are integral to the current structure of the author's courses. The first of these is cooperative learning with strategies drawn from Millis and Cottel (*32*). Permanent structured-learning teams of 3-4 students engaged in the cooperative-learning structure known as

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“Structured Problem Solving.” Following the recommendation of Millis and Cottell (*32*), student questionnaire responses were used to put students into permanent groups of 3-4 students with a mix of weak and strong calculus and physics backgrounds. Sometimes student interests were also considered to diversify groups. The roles for Structured Problem Solving were chosen based on the recommendations of Millis and Cottell (*32*). The “Leader” guides the group’s problem-solving efforts, the “Scribe” writes down the group’s work and answers, the “Reference Librarian” looks up information in the textbook as needed, and the “Wild Card” participates in the group work and fills in for another role as needed. In “Structured Problem Solving,” the instructor poses a question or problem with a time limit. Students must complete the specified assignment cooperatively using the assigned roles and be sure that all team members can serve as spokesperson to present the team’s results. The instructor randomly selected team members to work the problem on the board rather than giving a spoken account of the team’s work due to the nature of the assignments. The five components of cooperative learning as described by Millis and Cottell (*32*) are incorporated by giving suitable low-stakes exercises to groups of 3-4 students who are instructed to work cooperatively to complete them. Interdependence and individual accountability are encouraged by randomly choosing one student to present his or her solution for each problem so that all groups are motivated to make sure each student understands the solution of each problem.

The second active learning strategy incorporated is Just-in-Time Teaching. Strategies in this area were drawn from Simkins and Maier (*33*). Just-in-Time Teaching was developed by physics educators and can be described as a feedback loop between in-class activities and out-of-class experiences and/or assignments (*34*). Students are given a preparatory assignment to read, watch, or do something and then complete a web-based assessment of “JiTT exercises” before class. The student answers to the JiTT exercises are then used by the instructor to plan the day’s in-class activities.

Course Structure

The textbook used for the author’s flipped course is *Physical Chemistry: A Molecular Approach* by McQuarrie and Simon (*35*). The first semester of the two-semester sequence covers the failures of classical physics, the classical wave equation, the postulates of quantum mechanics, the particle in a box, the harmonic oscillator and rigid rotator, the hydrogen atom, methods of approximation, multi-electron atomic structure and spectroscopy, diatomic and polyatomic molecular structure and bonding, symmetry, and molecular spectroscopy. This corresponds to 12 of the 16 topics surveyed by Fox and Roehring (*13*). This includes Chapters 1-10, 12, and 13 of McQuarrie and Simon as well as the interspersed Math Chapters A-F. One or more sections are omitted from most of these chapters of the textbook. The second semester of the sequence covers properties of gases, the Boltzmann factor and partition functions, first, second, and third laws of thermodynamics, Gibbs and Helmholtz energies, phase equilibria, solutions, chemical equilibria, kinetic theory of gases, and rate laws and reaction

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mechanisms. This corresponds to the first 14 of the 16 topics surveyed by Fox and Roehring (*13*). This includes chapters 16-29 of McQuarrie and Simon as well as Math Chapters H, I, and J. Again one or more sections are omitted from most chapters of the textbook. Chapters 14, 15, 30, and 31 are omitted entirely. Some printings of McQuarrie and Simon omit the chapters called "Solutions 1: Liquid-liquid Solutions" (usually 24) and "Solutions 2: Liquid-solid Solutions" (usually 25) and renumber everything after chapter 23.

For each chapter, students were given a handout which identified the screencasts assigned for each day, the lengths and topics of those screencasts, and the corresponding section(s) or pages in the textbook. Because each screencast followed the corresponding section(s) of the book fairly closely, students had the option of reading the book instead of watching the screencasts, and a couple of students have done this in the three years of the author's flipped classes. Most students brought their textbook to class most days because they needed it as a reference for in-class exercises. The course grade was determined by 2 mid-term exams and 1 final exam (20% each), homework assignments (1 per chapter, 15% total), before-class warm-up questions (total 15%), and in-class cooperative learning exercises (total 10%). The physical chemistry lab is a separate two-credit course that students take after completing the two semester sequence described in this chapter.

Bergman and Sams' description of key components to a flipped class (*36*) was used to convert to a flipped format. The following sections describe each component of the course design.

Screencast Videos

During the first year of the flipped courses, 180 screencast videos were prepared. They were made with the author's existing lecture notes by lecturing to the computer and using the program Camtasia (*37*) to capture what was on the computer screen as well as the instructor's voice. The videos were uploaded to the course management system, Moodle. The next year they were all moved to YouTube (*38*) since Moodle won't include the videos in the backup at the end of the semester due to their size. The way the material is presented in any given screencast falls into one or more of three categories. The first category is similar to a PowerPoint slide show except that Mathematica is used to show slides on the screen with text, equations, graphs, figures, or other suitable materials and then use that material to explain concepts, discuss equations and figures, etc. The second category uses a Wacom tablet and a drawing program that came with the tablet called SketchBook Express (*39*). Figures or equations were drawn or written while they are discussed or short derivations or problems were worked by hand. The third category is where Mathematica is used to do derivations, symbolic or numeric calculations, or construct 2D or 3D graphs.

Student Preparation for Class

A link to each screencast video is posted, along with the Mathematica file that is used to prepare the screencast. (This is equivalent to "posting the slides.") For

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each class, the before-class student assignment is to watch 2-4 videos (average length after year 1 is 10. ± 3. min) and then complete a Moodle quiz composed of 4 “warm-up” questions. The first three questions are short essay questions addressing the material in the screencasts. The fourth question is always the “muddiest point” question: “Of the material in the screencasts, what was the most confusing point? If nothing was confusing, what was most interesting?” The warm-up question quiz closes in the morning on the day of the class when those topics will be addressed. Time is spent on the first day of class talking about how screencasts are a way for the instructor to give the students more of the instructor’s time and students are reminded of this on a regular basis. The combination of these reminders and credit for the warm-up questions resulted in student buy-in to the flipped approach and most students completed the before-class assignments.

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Instructor Preparation for Class and Class Time

Between the time that the warm-up question quiz closes and the time that class starts, the student answers to the warm-up questions are downloaded from Moodle and reviewed by the instructor. The activities for the day’s class are then planned. Class starts with a review of the warm-up questions, examples of student answers (names removed), and points of confusion or curiosity. After that a mini-lecture on material that was problematic or particularly confusing may be given. This is never re-covering the material in the same way as in the screencast video. It is sometimes just a different approach to the material but more often it is a higher level summary of the details that students got bogged down in while watching the screencasts. Cooperative learning exercises on that day’s material are also prepared and/or revised.

The majority of class-time is reserved for cooperative learning exercises. Consistent with the recommendations by Millis and Cottel (*32*), the group roles including “Leader”, “Scribe”, and “Reference Librarian” are assigned on a rotating basis. Each group gets a folder with a copy of each exercise for each student. The students of each group rearrange their desks into a circle and work together to complete the exercises. While students are working, the instructor circulates between groups checking student work, answering questions, and providing as little or as much coaching as needed. Near the end of class, dice are rolled to randomly choose students to present their work and answers for the exercises on the whiteboard at the front of the classroom. Sometimes after the student presentations of solutions, an exercise will be discussed further and how it relates to an assigned homework problem will be addressed.

Cooperative Learning Exercises

During the cooperative learning portion of the class, a variety of different types of problems and questions are used as cooperative learning exercises for "Structured Problem Solving." A few examples are included in Table 1. A type of exercise applied to derivation-based material is adapted from the concept mapping technique (*40*). An instructor-generated example is shown in Figure 1. Students are supplied with a sheet of equations, scissors, glue, and a large piece of colored paper. They are instructed to cut out the equations, arrange and glue them onto the colored paper, and then draw and label arrows explaining how the equations are related or transformed. Another useful exercise is an "equation organizer" grid where students are given a paper grid with row and column headings and instructed to fill in the grid by figuring out which equations belong where. This helps students answer their own question when "I don't know which equation to use" comes up.

Homework

One homework assignment is given at the beginning of each chapter. Each chapter's homework assignment consists of 3-8 problems. These problems are a mix of problems adapted from end-of-chapter problems in textbooks and the author's original problems. Each problem is specified as "Handwritten," "Mathematica," or "Handwritten or Mathematica." There are several different categories of problems used in homework. Many problems are the algorithmic type which involve identifying the equations and using the input data to calculate numerical results. Where possible, algorithmic problems include comparison of the calculation to experimental results or comparison of calculated results for multiple chemical species. Another major category involves symbolic math to obtain a purely symbolic result. These problems may be assigned as "Handwritten" or "Mathematica" depending on the nature of the symbolic manipulation. A few problems involve examination of mathematical expressions (such as differential equations) to classify them in some way. Where possible, the generation of 2D graphs, such as comparing functions, or 3D graphics, such as visualization of orbitals is included. The graphical analysis of numerical data to obtain a numerical result or the analysis of a graph (such as a phase diagram) to obtain numerical or symbolic results is also included. Homework problems which include the continuation of Mathematica work which was started in a screencast are used where possible. Other homework problems are based solely on one Mathematica document which is not tied to a screencast. Those documents generally include the explanation of concepts and examples as well as assigned problems.

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Table 1. Examples of Categories of Cooperative Learning Exercises

Category	*Example*
Simple numeric calculation	The threshold wavelength of copper turns out to be 266.6 nm. Calculate the work function for copper (in J and eV) and predict the kinetic energy of the ejected electrons (in J) if light of wavelength 254 nm is used.
Analyze qualitative and/or quantitative data to answer qualitative questions	Here is some data on standard molar entropies: $C_3H_{6(g)}$ (cyclopropane) 237.6 J K^{-1} mol^{-1} $C_3H_{8(g)}$ (propane) 269.9 J K^{-1} mol^{-1} $C_6H_{12(l)}$ (cyclohexane) 204.4 J K^{-1} mol^{-1} $C_6H_{14(l)}$ (hexane) 204.3 J K^{-1} mol^{-1} Draw Lewis structures for these compounds. Describe any trends you can observe. Describe any differences you can observe and suggest an explanation for those differences.
Short derivation	Use the equations $E_n = \frac{m_c e^4}{8 \varepsilon_0^2 h^2 n^2}$, $\Delta E = E_{n_2} - E_{n_1}$, $E_{photon} = h c \tilde{\nu}$ to show that the wavenumber of a hydrogen emission line is given by $\tilde{\nu} = \frac{m_e e^4}{8 \varepsilon_0^2 c h^3}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$.
Symbolic problems where algebra and/or calculus are performed by hand	Starting with $\left(\frac{\partial G}{\partial P}\right)_T$, show that $\overline{G}(T, P) = G^o(T) + R\ T \ln\left(\frac{P}{P^o}\right)$ for an ideal gas.
Terminology exercise	Write a definition for each of the following terms: symmetry element, symmetry operation, point group, matrix representative, matrix representation, basis.
Use of molecular models	Find the point group for each of the following molecules: cyclohexane (boat), tetraazidocopper (II) $[Cu(N_3)_4]^{2-}$ (N_3^-)'s are linear), cyclobutane (planar), cubane (C_8H_8 in a cube arrangement)
Mapping exercise	See Figure 1.

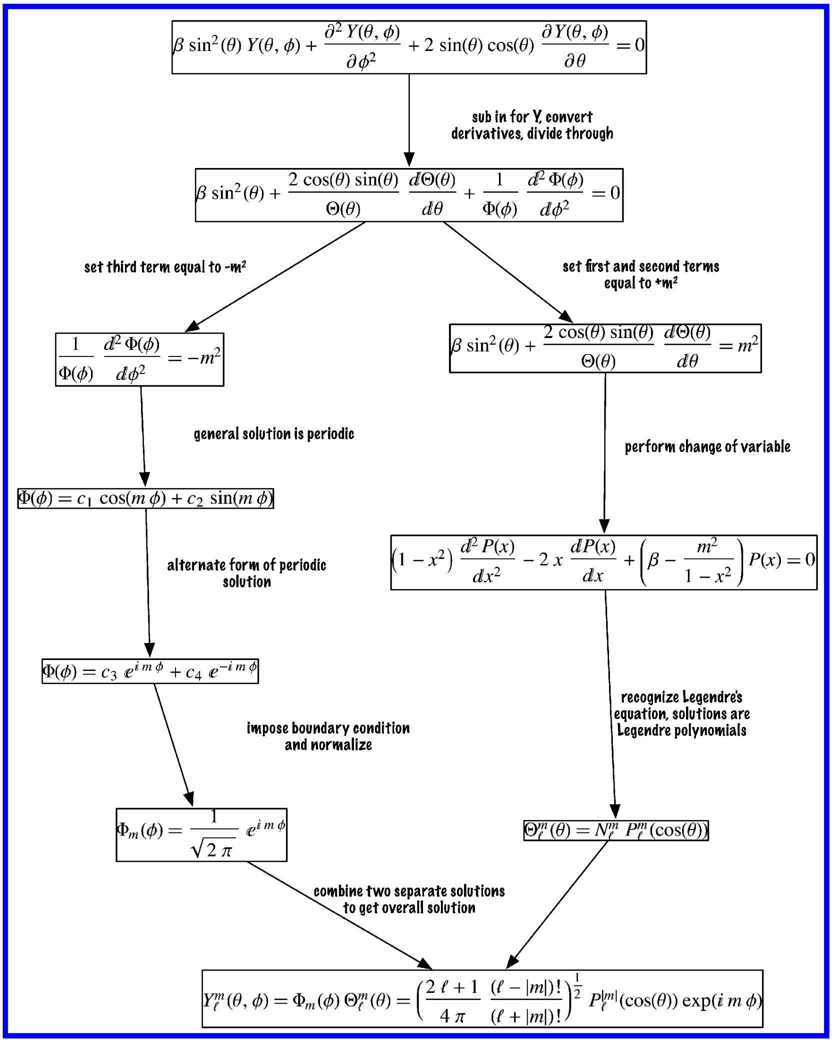

Figure 1. Example of a Mapping Exercise. The equations in boxes are supplied to students as a list. The unboxed text represents student explanations of the relationships between the boxed equations.

Exams

For each of the two semesters, two exams are given during each semester and a third exam is given during finals week. The exam during finals week of the spring semester is an ACS standardized cumulative exam over the whole year. All of the other exams have the same format. Each exam has two parts. The first part, worth about one-third of the points, consists of short problems done on paper with a pencil. A few of the problems are multiple-choice and the rest are essay questions or short problems. This part of the exam is focused on key concepts, understanding mathematical processes involved in obtaining important symbolic

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results, and physically interpreting numeric and symbolic results. Derivation type problems include a starting point and sometimes an ending point. Numerical calculations are generally not included. The second part of the exam, worth about two-thirds of the points, is open-book, open-note, and done both in Mathematica and on paper. This part of the exam includes mostly problems adapted from homework problems. Some problems are long and some are short but the focus is on using available and familiar resources and tools to do problems which are as new and as different as they can be made without losing the connection to cooperative learning exercises and homework problems. During this part of the exam, a student can request the instructor's assistance with finding typos and syntax errors by raising a hand. The instructor can usually find typos and syntax errors quickly and will tell the student "that isn't a Mathematica problem" if the problem is something else. This assistance during exams is a small price to pay for the level of difficulty of problems that can be put on the exam and that students can effectively complete. A study guide is provided for each chapter and consists of two lists of learning objectives. One list is for material that would appear on the first part of the exam and one for material that would appear on the second part of the exam.

Use of Symbolic Math Program in Screencasts

Using a screencast video to teach Mathematica combines the advantages of teaching students only the Mathematica that they need to know with a hands-on approach and removes the issue of different students progressing at different paces. A certain subset of the screencast videos contain a section where some type of problem or process is done in Mathematica. When a student watches that screencast, he or she opens the Mathematica file provided on the course management system. This file has the text shown in the screencast and sometimes starting functions so students don't have to type them in. The student then watches the screencast video, pauses the video when something is done in Mathematica, and reproduces the Mathematica work in his or her own Mathematica file. Most of the time students are able to reproduce what is done in the screencast because they have both the instructor's input and the correct output in front of them in the screencast video. One of the warm-up questions in the online quiz then instructs the student to email his or her file with the Mathematica work. All of the student files are reviewed by the instructor for mistakes before class. When the warm-up questions and answers are discussed at the beginning of class, any mistakes that are found in student Mathematica files are identified and a fix described. Students must go back and fix those mistakes to be successful on the homework. Many of the chapter homework assignments have a problem to the effect of "follow all instructions and answer all questions in the Mathematica file for Chapter X Topic Y." The topics that appear in the homework this way have additional problems interspersed with the screencast material or at the end that are closely related to the problems that were done in the screencast. A potential disadvantage of this overall approach is that students don't have the option of immediate assistance or feedback when they have a mistake or issue they can't fix. The solution to this is to keep the Mathematica sections in the screencasts fairly short.

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For the first few chapters of the first semester, all of the homework problems that must be done in Mathematica are closely related to problems done in a screencast using Mathematica. Students can use that screencast Mathematica work, which has been checked and corrected by the instructor, as a starting point for the homework problems. This further helps students develop their Mathematica skills and minimize the time spent fixing syntax errors and typos. Later in the first semester and extensively in the second semester, homework problems are assigned that must be done in Mathematica but where students have not seen a closely related example. The combination of reproducing Mathematica work shown in screencasts and re-using that work for additional problems gives students the Mathematica skills to tackle new homework problems effectively.

One last tool that is used to effectively incorporate the use of a symbolic math program into physical chemistry with minimum loss of time is the "computer lab session." For our three-credit class, we have a fourth hour each week for a recitation or review session. In the author's physical chemistry course, these sessions are used to meet students in the department's computer lab. Students are instructed to start the homework problems before the computer lab session so that they can get help with any Mathematica mistakes or issues or homework difficulties in general. The students who start the homework beforehand are able to quickly get the instructor's help with syntax errors and typos as well as broader questions and can often complete their homework during the computer lab session with minimal frustration and far less time than students used to spend on a homework assignment before the conversion to the flipped approach.

Lessons Learned

Below are some of the significant lessons the author has learned in the first three years of the author's flipped physical chemistry courses. While these lessons are not particularly novel, they may be helpful to someone considering the conversion to a flipped physical chemistry course.

ACS Standardized Exam

While the effectiveness of active learning strategies such as cooperative learning and Just-in-Time Teaching has been established elsewhere (*32*, *33*), it would be useful to have quantitative pedagogical research on the effectiveness of this specific approach to physical chemistry. The average class size for the author's sequence is 8.5 ± 3.0 students over the 8 years since the second sequence was initiated. For a sample size that small, the normal variability in measures of achievement is as large or larger than the improvement that might be expected from the incorporation of active learning strategies. Scores on the ACS cumulative exam given at the end of the second course are shown in Figure 2. No clear difference before vs after the conversion to the flipped classroom can be observed.

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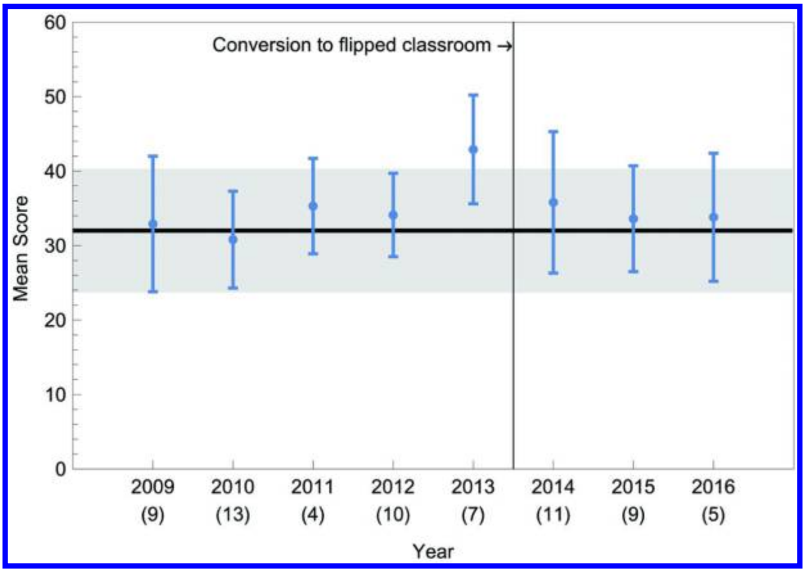

Figure 2. Mean scores on a cumulative ACS standardized exam. The gray box shows the national mean and standard deviation reported by the Examinations Institute. The number of students in the class is given in parentheses below the year.

Student Survey Responses

The use of active learning methods is still not widespread and students entering the author's flipped physical chemistry course were not generally familiar with the flipped classroom, cooperative learning, or Just-in-Time Teaching. For this reason, good communication was essential and students were asked to complete anonymous surveys. Results from these surveys are included here to illustrate student responses to the author's flipped classroom but do not address such interesting questions as whether students prefer the flipped classroom over a traditional lecture, students' overall impressions of the class, or the impact on student learning.

Table 2 shows a list of techniques used in the author's flipped classroom that were included in a a Likert-type scale survey. Twenty-five students were asked to indicate their level of agreement with the statement "This technique helped me understand and learn physical chemistry" with 1 being Strongly Agree and 5 being Strongly Disagree. The results are shown in Figure 3.

Table 2. Techniques for Likert-type scale survey.

Question number	*Technique*
1	screencasts in general
2	screencasts that used Mathematica to do calculus
3	screencasts that used Mathematica to plot 2D or 3D graphics
4	screencasts that used text and handwritten info and figures from the book
5	warm-up questions
6	cooperative learning (group) exercises
7	Mathematic demos
8	computer lab sessions
9	homework problems that use Mathematica to do calculus or graphics
10	homework problems that were handwritten

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In Figure 2, the question for which the most students chose Neutral, Disagree, or Strongly Disagree is number 5, “warm-up questions.” The fact that students were less likely to agree that warm-up questions help them learn physical chemistry did not lead to changes in the use of the warm-up questions because they are very useful to the instructor and a necessary component of the Just-in-Time Teaching method.

In addition to the Likert-type scale survey, two open-ended questions were given to 25 students:

> Please suggest one thing that could be improved about one of the techniques above.
> Please describe one thing that you liked about one of the techniques above.

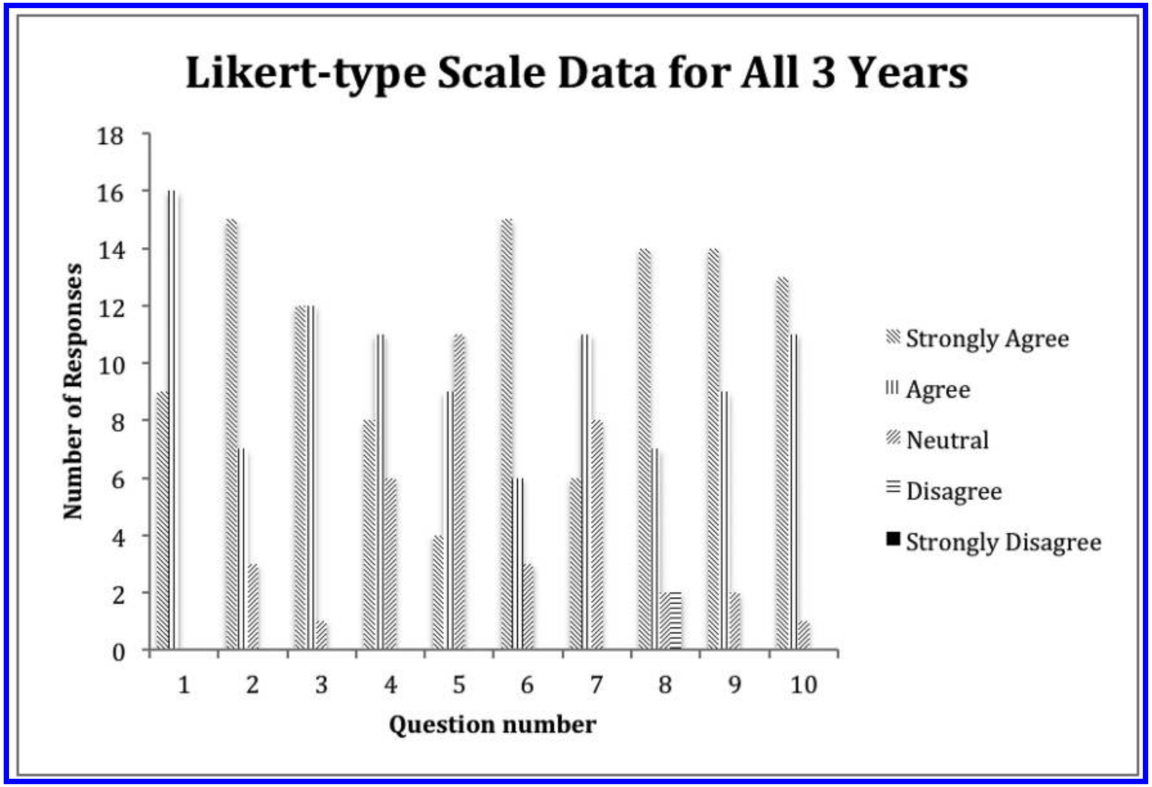

Figure 3. Responses to the Likert-type scale survey. Question numbers refer to Table 2.

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Muzyka and Luker; The Flipped Classroom Volume 1: Background and Challenges
ACS Symposium Series; American Chemical Society: Washington, DC, 2016.

Student responses to these questions over the three years of the flipped class were grouped into categories as shown in Tables 3 and 4. The student responses categorized in Table 3 represent numerous valuable suggestions from students on ways to improve the author's implementation of the flipped classroom but no broad areas of discontent or the same problem reported by more than three students. All three of the responses related to screencast length were received in the first year and more than a dozen of the longest screencasts were divided into parts or shortened as a result. Two of the three responses relating to warm-up question content were received in the first year and influenced the revision of warm-up questions in subsequent years. Novak and Patterson list 5 characteristics of effective JiTT questions (*34*) including that they "require an answer that cannot be easily looked up" and that they "require that students formulate a response, including the underlying concepts, in their own words." These student comments in this category are consistent with the difficulties the author has had in constructing such questions for physical chemistry. Many of the warm-up questions do not possess the characteristics listed by Novak and Patterson (*34*) and simply check to see if the student has watched the assigned screencasts.

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Table 3. Summary of student responses to "Please suggest one thing that could be improved about one of the techniques above."

Category of response	*# of responses*
Length of screencasts	3
Details of screencast content	3
Details of cooperative learning	3
Warm-up question content	3
Details of use of Mma	3
Unique responses	7
No response	3

Table 4. Summary of student responses to "Please describe one thing that you liked about one of the techniques above."

Category of response	*# of responses*
Use of Mma	9
Use of screencasts	3
Use of cooperative learning	7
Use of screencasts & cooperative learning	2
Unique responses	1
No response	3

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Because the 25 responses categorized in Table 4 represent a small number of unique categories, some examples of student responses are given in Tables 5 and 6. Table 5 shows a selection of student responses to the survey item: "Please describe one thing that you liked about one of the techniques" on various aspects of the flipped class structure. These student responses suggest that the students had positive impressions of the screencasts, cooperative learning in-class exercises, and the overall structure of the author's flipped physical chemistry courses. Table 6 shows a selection of student responses (to the same survey item) that pertain to the use of Mathematica. These responses suggest that students believe the use of Mathematica helps improve their conceptual understanding.

Insight into Student Confusion

Another lesson learned in the flipped physical chemistry course is about the effectiveness of the "muddiest point" warm-up question. When an instructor asks a classroom of students if there are any questions after a section of lecture, a few students may ask questions or for clarification but that doesn't mean that most of the class understands the lecture material. The lecture setting inherently limits the ability of the instructor to determine whether or how well students understand the material by the questions that students do or don't ask in a lecture setting. On the other hand, when students are presented with the question "what was the most confusing thing in this material?" in an online quiz as an essay question, the responses that the students give in the privacy of their own web browser can yield a profound insight into how well students actually understand new concepts. Student engagement with the screencast videos varies just like student engagement in lecture varies. When even the most conscientious students are confused by a new concept, the concept clearly needs a different, better approach.

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Table 5. Student responses to screencasts and cooperative learning

"Screencasts are such a valuable tool for someone like me. I do not learn well the first time that I see new material. With these screencasts, I never have to see new material for the first time in class. I also learn very slowly, so it is nice to be able to pause you!"
"I like that we could use the videos to go back to. You can't do that with in class lectures so if something wasn't clear when you went over it in class, it was very nice to go back and watch them again."
"I really like the screencasts. I think its nice being able to go back and review a topic if I am struggling. Plus then I don't have to light my paper on fire trying to keep up with the professor during lecture. I can take my time, pause, rewind, etc. if needed."
"Group works were great. The fact that one would listen to the screencast and come to class with an idea of what to expect, were made more concrete after the discussions we have in class along with the group works done."
"I loved the use of class time. Having the lectures move out of class and problems to work within groups is genius, I wish more teachers would do this."
"The in class cooperative learning exercises helped the most with the application of the course material."
"The group exercises were great in that it helps to actually work through some problems together and being able to ask questions and clarify."
"I do like being able to review the screencasts at any time to pick up information I may have missed. Mathematica has also been a very powerful tool to learn how to use."
"Considering the complexity and amount of information we cover in this course, the screencasts and Mathematica help so much. The in class exercises are also very helpful."
"I like how we do screencasts out of class and come to class to clarify and can focus on what we don't understand."

Difficult Homework Problems

In the author's flipped physical chemistry courses, the students still struggled with homework problems. In the ideal scenario for a traditional lecture course, a student meets a new concept reading the textbook before class, hears more about that concept in lecture, observes an initial problem or example in lecture, and finally explores that concept deeply and practices it in one or more homework problems.

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Table 6. Student responses related to Mathematica

"I liked learning the calculus in [Mathematica]; I thought that it was more helpful to understand the major concepts then to try to push my way through hard calculus."
"I really liked the fact that we used Mathematica to do a lot of the complex integration and math. It enabled me to focus on the concept of the chapter rather than try to understand and freak out about trying to understand math I have never used."
"I liked doing some of the more complicated math in [Mathematica] since I lack the background in it."
"I liked drawing in Mathematica. It helped me understand the orbitals and interactions more."
"Using [Mathematica] to do extensive calculus. This allowed me to focus on what the math operations mean and signify in terms of chemistry and not having to focus on an extensive differentiation/integration."
"[Mathematica] allowed for complex problems to be solved more easily and simply."
"Mathematica was the best ever!"
"I liked the computer lab sessions because there was help for the homework."

Unfortunately, this is not always what happens. There may not be examples that are both useful and doable on the board in a reasonable length of time. Students often don't do the assigned reading. Instead of the ideal scenario, the student meets a new concept in lecture and then attempts one or more homework problems on the concept. The introduction of the concept in lecture may be at a rather low level and the homework problem may be at a rather high level. The distance between these two leaves students struggling to get started on the homework problems. This is particularly true if the homework problem is not well-connected to the concept, as some end-of-chapter problems in textbooks are.

In the author's flipped class, the plan is that the student meets a new concept in a screencast, answers a warm-up question about the concept before class, does one or more cooperative learning exercises on the concept in class, explores the topic deeply and practices it in the homework problems, and finally ties it into the big picture conceptually.

Two different open-ended questions about homework were used on different surveys. One question was "Do you feel prepared for the homework assignments? Do you have any suggestions for making them more useful?" A second was "When you sit down to do the homework at home, what is your biggest challenge?" A total of 15 students were given surveys with either of these two questions. Table 7 shows four examples of student responses to these survey questions pertaining to homework. These responses suggest that students value the connection between in-class exercises and the homework but that the connection is not always present and/or strong enough to get them started on the homework. This is an area of on-going development.

Table 7. Student responses to questions about homework

"Some homework sets were definitely more difficult than others. I think the [cooperative learning exercises] were a big help for the homework this semester, they provide some specific examples which can be helpful to the homework process."
"When we were doing thermodynamics for some reason those homeworks were much more difficult that quantum mechanics and chemical equilibrium/kinetics. There were times I would see the homework and not even know where to begin or what to try to work my way through the question. That was never an issue with quantum or chemical equilibria/kinetics."
"The hardest parts of homework are the few cases where it doesn't seem to have anything in common with in class exercises; again I can't remember exact ones."
"I think the challenge with the homework is that while they are similar to [cooperative learning exercises], they are often more complicated and it can be difficult to "fill the gap" between the [cooperative learning exercise] and the homework."

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Scope of the Physical Chemistry Sequence

Another lesson learned in the flipped physical chemistry course is just how vast the scope of the modern physical chemistry course is. There has been discussion about what to include in the physical chemistry course (*41–43*). The question "What about physical chemistry is the biggest factor in making it difficult for you?" was given to a total of 20 students. Table 8 shows eight student responses to this question. These responses indicate that student perceptions about the difficulties of physical chemistry are similar to those identified by Sozbilir (*4*): too much content, abstract concepts, and the pace of the course. With the introduction of material moved out of class time and into screencasts, students' lack of understanding can no longer be blamed on their unwillingness or inability to pay attention in lecture. The students know they have the option to watch each screencast as many times as they wish to and some do watch them repeatedly. Student responses suggest that the problem is that many concepts are introduced at a fire-hose pace that really is difficult to keep up with, even for the most conscientious students. This problem is not unique to physical chemistry, certainly, but a flipped class has made it much more difficult to ignore. The author's approach has been to eliminate more and more parts of the chapters covered to streamline and focus the presentation of the key concepts.

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Table 8. Student responses on the difficulty of physical chemistry

"too much material was the main culprit. But I do not see how else you can cut it down without losing essential topics. There were already 5 whole chapter plus the parts of chapters we did not cover."
"for me it was too much information and the fact that you kind of get rammed with new and confusing concepts but then again that's all material when your learning it, but it was a lot of information to take in and learn. sometimes I felt like we moved from subject to subject and I had barely grasped the one before making the one next more difficult."
"Too much material, but that cannot be avoided."
"I think the abstract concept was hardest for me. I have a hard time visualizing concepts sometimes when it's basically completely hypothetical."
"I think the abstract concepts are usually the hardest part. Some of the calculus from the quantum physics was overwhelming sometimes, but again it mostly came down to the abstract way you had to think about the problems."
"I think just trying to keep it all straight was the most difficult part."
"The hardest part though for me is how if you miss something its hard to come back from that since everything builds around that; but in that way its like most other chemistry classes."
"What I thought was really hard is the fact that every thing builds on one another. So if something took a while to understand the material became really confusing and hard. And now basically remembering the whole year of p.chem, thats the biggest challenge now."

The Synergy of a Symbolic Math Program and Screencasts

The author's use of a computer and a screen in the computer lab to teach students to use a symbolic math engine predates the author's use of screencasts by five years. When students learned to use Mathematica by watching demonstrations of the instructor on a screen and then working with example code, computer lab sessions involved the author assisting students with finding typos and syntax errors a large fraction of the time and assisting students with figuring out how to use a symbolic math program to do physical chemistry problems a small fraction of the time. With the introduction of screencasts where use of Mathematica is demonstrated and students reproduce that use of Mathematica as a before-class activity and it is checked by the instructor, the relative proportions of the assistance in the computer lab have reversed with only a small fraction of the time devoted to helping students fix typos and syntax errors and a much larger fraction of the time devoted to helping students figure out how to use Mathematica to do physical chemistry problems. The magnitude of this change was unexpected by the author. The seemingly trivial act of reproducing what they observe in the screencasts familiarizes students with the syntax of Mathematica and builds their Mathematica skills in an incremental way. They don't make as many typos and syntax errors as the author's physical chemistry students used to make.

Next Step

The next objective for improving these physical chemistry courses is to make better screencast videos with a pedagogically sound approach. The current screencast videos were made by "lecturing" to the computer. They are more useful than traditional lecture only in the sense that they are outside of class time and that students can watch them as many times as they wish. The initial screencast videos were prepared by lecturing to the computer using the existing lecture notes and capturing this to video using the screen-capture program Camtasia. This approach was relatively time-efficient and allowed the preparation of all of the videos in one academic year. Putting a block of explanatory text on a slide sometimes seems like a service to students because it provides the students with the instructor's best explanation in an easily accessed form. However, spoken information and redundant text information presented simultaneously overload students' working memory (*44*). In *Multimedia Learning* (*45*), a number of studies are summarized on how to make multimedia learning more effective. Several of those studies address the negative impacts of this "redundancy effect". Showing students a slide of text at the same time that audio is happening imposes a "cognitive load" in processing auditory and text information simultaneously. A better approach in terms of cognitive load is to show a graphic or other non-text resource while discussing the concept (*45*). A review of the relevant literature on how to introduce complex concepts is in progress in order to plan a new approach to physical chemistry screencast videos.

Conclusions

Survey responses suggest that students believe the techniques used in the author's flipped classroom help them to learn physical chemistry. Responses also suggest that students believe use of a symbolic math program leads to better conceptual understanding. The author has gained insight into when and why students struggle with physical chemistry but the issues identified in by other investigators remain: too much content, abstract concepts, and the fast pace of the course. The author's experiences assisting students in the computer lab suggest that screencasts are a more effective way to teach students to use a symbolic math program for physical chemistry.

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Chapter 5

Team-Based Learning in Physical Chemistry

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Team-based learning (TBL) is a flipped-class pedagogy that includes all the elements of cooperative learning. This chapter begins by explaining the characteristic elements of TBL. The main body of the chapter then discusses how a physical chemistry (thermodynamics) course was converted from traditional lecture format to TBL, and what it was like to teach the course. ACS exam data presented here demonstrates that more material was covered in the converted course without sacrificing learning. In addition, survey data indicates that students considered the elements of the course helpful to their learning. The chapter closes with a few words of advice for faculty developing TBL courses.

Background

I taught physical chemistry: thermodynamics for more than a decade using a traditional lecture format. Despite trying to make the lectures animated and relevant, I found that the students were often listening passively; occasionally a student would even fall asleep. In addition, they seemed to lack long-term retention and the ability to transfer their knowledge to new situations. Most students were unable to apply their knowledge to a new context when they later took the physical chemistry lab. It was time to try some form of active learning.

First, I tried using scaffolded instruction, also called "I do, we do, you do" (*1*). In this technique the instructor demonstrates a skill to the students (I do it), students practice that skill with the instructor's help (we do it together), students work in groups (you do it together), and finally students practice the skill by themselves (you do it alone), usually by doing homework. I found that using "I do, we do, you do" was effective. The *we do it* phase was an excellent way to discover and

correct common misconceptions, and the *you do it together* phase allowed for peer instruction. However, both these phases took a **lot** of class time. If I had implemented scaffolded instruction consistently, the amount of content covered would have plummeted.

The flipped classroom model resolves the time conflict mentioned above. In this strategy, the *I do* phase of a lesson occurs before class, using a combination of readings and videos. Class time is spent mostly on the *we do* and *you do it together* phases, which prepare students for independent work in the *you do alone* phase. This strategy has several advantages. Since students watch the lecture on a computer, they can speed it up or slow it down as needed. The struggling student may watch a lecture several times. In class, the students have plenty of time to practice problem solving in a setting supported by their professor. However, this strategy also has potential disadvantages. Students may not watch the videos and come to class unprepared, and thus be unable to take full advantage of in-class learning activities. Also, if in-class learning activities include a group component, students may not participate in a constructive manner. Successful flipped classroom pedagogies have elements that address these concerns. One such strategy is Team-Based Learning (TBL).

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Team-Based Learning: An Introduction

TBL was developed more than thirty years ago to improve learning in large business school classes (*2*). It was soon adopted in medical schools (*3*) and in the last decade it began to be used in law schools (*4*), nursing schools (*5*), pharmacy schools (*6*), and undergraduate classes (*7*, *8*). TBL has several distinguishing characteristics; a brief summary of these is given below.

Large, permanent, instructor-selected teams: Teams consist of 5 to 7 students. Self-assembled groups may have unequal distributions of skills and tend to include pre-existing cliques that hinder team development (*9*). To prevent these problems, teams are chosen by the instructor. Teams mature and become more effective over time (*10*), and so the teams in TBL are permanent to allow time for this development to occur.

Peer assessment of team members: One potential problem with teamwork is social loafing (also called free riding or hitchhiking): students may come to class unprepared, and rely on the others in the team to do all the work. TBL uses peer assessment of team members to minimize this tendency.

Grade weights decided by consensus: Students often are nervous about the weighing of individual and team portions of their grades. To allay those concerns, the syllabus in a TBL course lists ranges, rather than single numbers, to describe how much each item in the course is worth. On the first day of class, students work in their teams, discussing how much each item should be worth. Afterwards, the instructor leads a whole-class discussion, and the grade weights are decided by consensus.

The readiness assurance process: Every unit of instruction begins with a readiness assurance process, which is designed to ensure that the students are

prepared for in-class learning activities. At the end of readiness assurance, students are ready to begin working with the materal at the application level. The instructor posts a preparation guide that may include readings, videos, learning objectives, and exercises. The students use their out-of-class time to prepare for the unit. The first class meeting of the unit is devoted to a Readiness Assurance Test (RAT). This test consists of multiple-choice questions that students will get right if they have fully mastered the material in the preparation guide. The students first take the test individually, to ensure individual accountability; this portion of the test is referred to as the individual Readiness Assurance Test (iRAT). When taking the test, they mark their answers on both the test and on a separate answer sheet. When the students are done working, the instructor collects their answer sheets, but the students retain their tests, and assemble into their teams. They then re-take the test as a team. This section of the test, the team Readiness Assurance Test (tRAT), encourages students to explain their reasoning to each other, and thus deepen their understanding.

As the teams are working on the tRAT, the instructor observes their work and listens to their discussions. When the teams are done working, the instructor collects the tRAT answer sheets, and looks them over to see which questions caused teams the most trouble. Meanwhile, the teams have the option of writing an appeal for any questions that they think are ambiguous, incorrect, or outside of the skill set addressed in the RAT preparation guide. The appeal process is open book, and thus encourages students to review yet again the material that is hardest for them. The instructor may address the appeals on the spot, or after class. After the instructor collects the appeals, the class as a whole discusses questions that teams missed. The instructor guides the discussion, making sure that misconceptions observed during the tRAT are addressed. The students are now ready to move on to the main stage of TBL, application exercises.

Team Application Exercises: The rest of the unit is spent doing team-based application exercises. The application exercise is a chance for the students to apply the basic principles learned or reviewed during the readiness assurance process. Each unit has 3-5 class meetings devoted to application exercises, so they comprise the main body of the course. In each application exercise, the teams are confronted with a single overarching choice: what is the appropriate treatment for this patient? Should the plaintiff succeed in court? After working the first two-thirds or so of a class meeting, the teams simultaneously report their choices. Then, the teams debate each other on the merits of their choices. Application exercises are designed using four criteria, the “four Ss”: same, significant, specific, and simultaneous (*9*).

- *Significant*: The problem must be relevant to the students. This is especially important for a topic such as physical chemistry, which students tend to think is too abstract. Ideally, the problem will be placed in a real context and be difficult enough that one student would be quite unlikely to solve it successfully.
- *Same*: All teams are given the same scenario. For instance, they may be asked to design a primitive power plant and assess its efficiency, and determine if it is enough to supply a certain amount of power. The students know that all teams will be reporting out solutions to the same

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problem, and that they will have to defend their conclusions about the problem.

- *Specific*: The team must make a specific choice at the conclusion of the problem. Sorting through data in a rich context and using the result to make a specific choice engages high levels on Bloom's taxonomy.
- *Simultaneous*: All teams must report their choice simultaneously, typically by having one team member hold up a color-coded card. Sequential reporting would allow teams to alter their choices based the responses from other teams. Simultaneous reporting prevents this, which means that the report is a real check for understanding. Some instructors use the team answers only for formative assessment; others assign a grade based on the team choices. In addition, the teams usually do not all pick the same choice. The lack of consensus stimulates the whole-class discussion that follows.

After the teams have revealed their choices, the class discusses the merits of the different choices. The instructor guides this discussion, so that the students themselves explain their pitfalls, and how they worked their way out of them. Most TBL courses have 3-5 class meetings devoted to application activities per unit.

Overall allotment of class time: Typically, about 20% of each unit is devoted to RATs, with the balance spent on application activities. TBL units do not necessarily end with an exam. However, some faculty do end each unit with an exam.

Using TBL To Teach Physical Chemistry

Designing a TBL Course

Backward course design (*11*) was used to convert the course from direct instruction to TBL. First, I wrote course learning objectives, and wrote first drafts of exams that mapped to those learning objectives. At our university, physical chemistry is taught as a three-course sequence, with each course taking one 10-week quarter; the first quarter is chemical thermodynamics. For first incarnation of the course, I divided the course into five two-week units, each beginning with a RAT and concluding with an exam. I designed application exercises that would develop the skills needed to succeed on the exams. Finally, I wrote RATs for each unit that included the basic skills needed to complete the application activities. In general, students were expected to review knowledge from prerequisite courses, learn vocabulary, and acquire simple skills during the Readiness Assurance Process. Difficult skills were developed after readiness assurance, during team application activities.

Implementing a TBL course

In the following section, I explain how I implemented my first TBL course, and give examples from a typical unit. The first course had 55 students, and met

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three times a week for 50 minutes. A few aspects of my course differ from the standard TBL implementation; these differences are specified in the text.

The First Day of Class

It is important to explain to students why non-traditional pedagogy is being used in the course (*12*, *13*), so two pages of the syllabus are devoted to this. On the first day of class, after pointing out that most facts are readily available on the internet, I asked the students, "what are valuable assets in an employee?" After a short discussion, the class agreed on several items, including problems solving skills and teamwork skills. At this point, we went over the syllabus, and I pointed out how the various aspects of TBL are designed to develop those skills. I also asked them their opinion on teamwork. Many students expressed reluctance to do teamwork, and mentioned bad experiences they had in past classes. After hearing from the students, I pointed out the various aspects of TBL that are designed to prevent the sort of problems they had mentioned.

My class deviated from TBL courses described in the literature in that we did not do the grade-weighting exercise; when designing the course, I thought that it would take too much time from content. In retrospect, I have found that there is plenty of time, since so much content is moved outside of class. Future offerings of the course will include the grade-weighting exercise.

Team Formation

Because students add and drop the course during the first week, team formation occurred at the end of the week. CATME (*14*), a website devoted to team formation and evaluation, was used to form the teams. After uploading my roster, three questions were selected for a short survey in CATME asking the students their gender, overall GPA, and grade in a prerequisite course (integral calculus). The team formation tool within CATME allows the instructor to group or distribute students who share similar answers on survey questions. The default setting, which we used, does not put female students on teams in which they are outnumbered. The GPA and grades were set to distribute evenly between the teams. Thus, all teams were of equal ability. Team assignments were sent out at the beginning of the second week of the course.

RAT Preparation Guide

Each preparation guide consisted of learning objectives, reading selections, text exercises, and videos. The learning objectives were not the learning objectives students needed to know at the end of the unit; rather, they were skills the students would need to *begin* working with the material during the application exercises. The students had only three days to prepare for a RAT, as units typically end on a Friday and the RAT for the next unit was on the following Monday.

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Thus, the reading selections had to be short. The iRAT preparation guide for the third unit in our physical chemistry course is shown in Table 1; the readings and exercises refer to our textbook (*15*). The videos were whiteboard screencasts either recorded in my office using a Wacom tablet, computer, and screencasting software, or at home using an iPad and a screencasting app. They were posted to the learning management system (LMS) for the course. The videos have been moved to YouTube, as former students have asked me for access to the videos.

Table 1. Readiness Assurance Preparation Guide

Category	*Items*
Learning Objectives	You should be able to explain why ideal gases or solutions mix, calculate the change in S, H, and G for mixing of ideal gases or solutions, use Raoult's law to estimate the vapor pressures of solutions from composition or vice-versa; use Gibbs' phase rule to calculate the degrees of freedom present in a system, extract which phases are present, their compositions, and their relative amounts from binary phase diagrams, and be able to relate the shape of a binary phase diagram to the deviation from Raoult's law for a system.
Text reading	Chapter 5A-C and chapter 4 section 4A.2b
Videos	Ideal gas mixing, Ideal Solutions, Raoult's Law, Gibb's phase rule, Liquid-Vapor phase diagrams
Text exercises	Chapter 5 problems: 5A: a exercises 4-6; 5B: a exercise 2; 5C a exercises 1,7.

iRAT

On the Monday of the second week of the course the students took the first RAT. The iRATs are individual multiple-choice tests. Since the entire Readiness Assurance Process (iRAT, tRAT, appeals, and discussion) needs to be done in one class period, the iRAT portion of the test was short; the goal was that it take just over one-third of of the class period. The questions were straightforward enough that any student who had thoroughly studied the RAT preparation guide could answer all questions correctly. To ensure this, most iRATs were written ahead of time, and then the preparation guide was written accordingly.

An excerpt from the RAT from third unit is shown in Figure 1. These questions test student's qualitative knowledge of ideal solution theory, specifically that the mixing of an ideal solution is driven by entropy rather than enthalpy. The students need this background knowledge to be able to successfully complete the application exercises in the unit.

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Dodecane and decane form an ideal solution. We mix 800 mL of dodecane with 200 mL of decane. Use this information to answer the next three questions.

1. What is ΔG for this process?
    a. Negative
    b. Positive
    c. Zero
    d. Impossible to tell

2. What is ΔH for this process?
    a. Zero
    b. Negative
    c. Positive
    d. Impossible to tell

3. What is ΔS for this process?
    a. Equal to ΔS surroundings
    b. Impossible to tell
    c. Negative
    d. Zero
    e. Positive

Figure 1. An excerpt from the RAT for the third unit in our physical chemistry course is shown above. Note that these questions test the students' mastery of the first two learning objectives in the preparation guide.

A second excerpt from the same RAT is shown in Figure 2. These questions test the student's ability to determine three quantities from a phase diagram (*16*): which phases are present, the composition of each phase, and the relative amounts of each phase. Since several of the application exercises use phase diagrams, these skills must be mastered during the Readiness Assurance Process.

tRAT

After turning in the Scantron answer sheets from the iRAT, the students assembled into their teams. Each team was given an Immediate Feedback Assessment Test (IF-AT) form for the tRAT. IF-AT forms are scratch-off cards in which the correct response, hidden under the scratch-off coating, is indicated by a star (*17*). The students scratched off answers until they uncover the star. Using these forms has several advantages. First, research indicates that students can learn a great deal during testing if they receive immediate feedback (*18*); when IF-AT forms are used, all students leave the room knowing the correct answers. Because the students scratch off answers until they are correct, instructors can assign decreasing partial credit for answering on the second or third try. Since the

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RAT questions each had 4 or 5 possible choices, teams got four points if they got the correct answer on the first try, two points on the second, and one on the third. This system gives the team an incentive to reconsider and discuss their reasoning after finding out their first (or second) choice for the answer was incorrect. The forms also encourage development of good team dynamics. For instance, one member of the team may forcefully advocate for an answer that turns out to be incorrect, or a quiet student may be ignored even though he or she knows the correct answer. In either circumstance, the team learns to hear everyone out, and base decisions on reasoning, not personality.

My course deviated from TBL courses in the literature in that I did not include an appeals process. On reflection, this was a mistake, as the students would engage the material while researching and writing the appeal, which would result in further learning. In the future, I plan to take written appeals, and post responses in the course LMS.

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Application Exercises

All class meetings between the RAT and exam for that unit were taken up by team-based application exercises; typically, this would be four class meetings. Each class started with a short (approximately five-minute) lecture to provide context and motivation for that day's application activity. The students then assembled into their teams; each team was provided with the application activity worksheet. The top of each worksheet included data; some also included a figure or a scenario. The figure and data for an example application exercise, *Phase Craze*, are shown in Figure 3 and Table 2.

Figure 3 is the solid-liquid temperature-composition phase diagram (*19*) for lead solder. Table 2 includes all data (*20*, *21*) needed to complete the exercise. The objective for the exercise is for students to connect the concepts of phase diagrams, non-ideality, chemical potential, and activity coefficients for non-electrolyte systems.

In TBL courses found in the literature, each application exercise is framed by the choice the teams have to make at the end of the exercise—the 4-S question. My application activities each had two of these 4-S questions—one mid-way into the exercise, and one at or near the end. These are shown in bold in Table 3. For both of these questions, the teams simultaneously reported their answers.

In addition to these questions, the worksheet also included intermediate questions which help to guide the team toward a solution if they are answered correctly. The teams did not report out their answers to these questions, but I used my observations on their work to decide when and how to intervene. This decision takes some judgement: fruitless struggle can frustrate students so much that they give up. On the other hand, students grow intellectually when they get stuck working a problem, and then think their way out of it.

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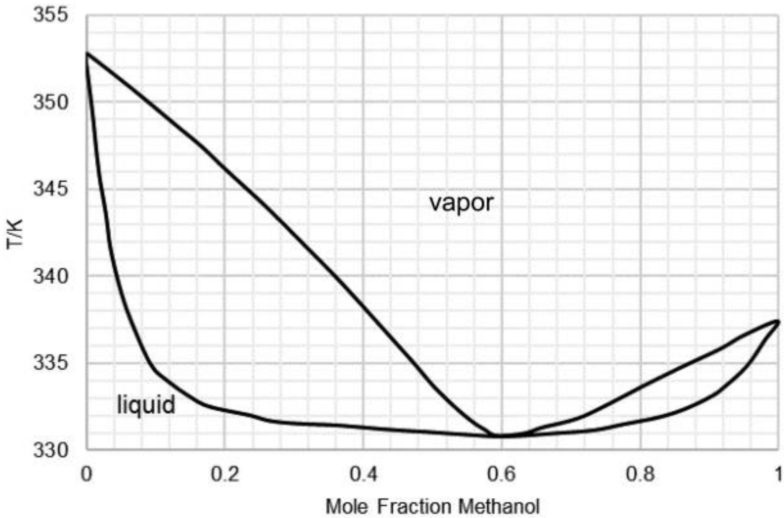

5. A sample with mole fraction of methanol 0.44 is heated to 334 K. What is the mole fraction of methanol in the liquid phase?
   a. 0.12
   b. 0.44
   c. 0.49
   d. 0.82
   e. 0.94

6. A sample with mole fraction of methanol 0.44 is heated to 334 K. What fraction of the sample is liquid?
   a. 0.14
   b. 0.29
   c. 0.44
   d. 0.84
   e. 0.71

7. How would you categorize this system with respect to Raoult's law?
   a. Impossible to tell
   b. Negative deviations
   c. No deviations
   d. Positive deviations

Figure 2. A second excerpt from the RAT for the third unit in our physical chemistry course is shown above. Note that these questions test the students' mastery of the last four learning objectives in the preparation guide. (The phase diagram is adapted with permission from reference (16). Copyright 1969 American Chemical Society.)

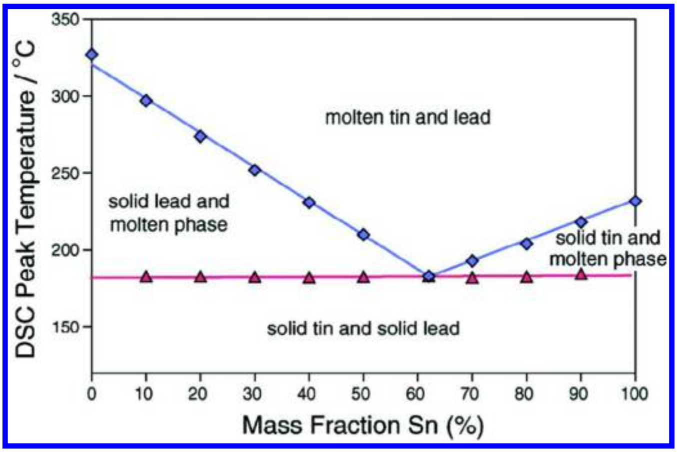

Figure 3. The phase diagram of lead solder was used by students during an application exercise. (Reproduced with permission from reference (19). Copyright 2012 American Chemical Society.)

Table 2. Readiness Assurance Preparation Guide

Material	*Tm (K)*	*Molar Mass (g/mol)*	$\Delta_{fus}H°$ *(kJ/mol)*
Tin[a]	505	119	6.61
Lead[b]	599	207	4.78

[a] Jones (2006), [b] Fleszar (2001)

While the teams worked, I monitored their progress and took notes on their discussions. It was difficult to avoid the temptation to speak when teams started to go down the wrong track, but was important to do so. For the most part the students would persevere, and it was gratifying to see them work their own way out of conceptual dead ends. Occasionally, I could tell that some teams were spinning their wheels or getting frustrated, and would ask a clarifying question to prod them in the right direction.

When all teams had finished the first inter-team specific-choice question, they simultaneously reported out. For many of the exercises, teams had to choose from just a few options, and they reported out by holding up color-coded index cards. Other exercises required a numerical calculation, and in those cases they wrote the answer on a card before holding it up.

Usually, not all teams agreed, and a robust discussion ensued. The discussion continued until all the teams agreed on the correct answer, and could explain why they chose it. The teams then went back to working on intra-team discussion questions until they finished the second inter-team specific-choice question at the end of the worksheet.

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Table 3. Application Exercise Guiding Questions

Question	*Discussion*
1. Consider a system with tin mass fraction of 0.30. Calculate the mole fraction of *lead*.	Intra-team
2. Consider a system with tin mass fraction of 0.50. Calculate the mole fraction of *lead*.	Intra-team
3. Suppose that tin and lead form an ideal solution in the liquid phase. Calculate the freezing point depression of lead when the mass fraction of tin is 0.30.	Intra-team
4. Suppose that tin and lead form an ideal solution in the liquid phase. Calculate the freezing point depression of lead when the mass fraction of tin is 0.50.	Intra-team
5. Compare your results from number 3 and 4 with the phase diagram. Is the liquid phase ideal? Explain your reasoning.	**Inter-team**
6. In the liquid phase, are the tin- lead interactions more favorable, less favorable, or equally favorable than the average of the tin- tin and lead- lead interactions? How do you know?	Intra-team
For the rest of the worksheet, please use a *Raoultian standard state*.	Intra-team
7. Use the phase diagram data to calculate the activity of lead in the liquid phase when the mass fraction of tin is 0.3.	Intra-team
8. Use the phase diagram data to calculate the activity *coefficient* of lead in the liquid phase when the mass fraction of tin is 0.3.	Intra-team
9. Use the phase diagram data to calculate the activity of lead in the liquid phase when the mass fraction of tin is 0.5.	Intra-team
10. Use the phase diagram data to calculate the activity *coefficient* of lead in the liquid phase when the mass fraction of tin is 0.5.	**Inter-team**
11. Are your answers to numbers 10 and 8 compatible with your answer to number 6? Why?	Intra-team
12. Compare the size of your answers to numbers 8 and 10 and draw a general conclusion.	Intra-team
13. Suppose that the regular solution model can be applied to this system. Estimate the value of δ.	Intra-team

Many application exercises, including the one shown in Table 3, had a few intra-team discussion extension questions at the very end. Teams that finished early could work on these while waiting for the other teams to finish; the material in them is useful, but not required to attain mastery of the learning objectives for the unit.

Once all teams had finished the second inter-team specific-choice question, the teams simultaneously reported out their choices, and then debated the answer. I guided this discussion to ensure that all the important points for the day were

covered. When the discussion concluded, a brief summary was provided before class was dismissed.

End of Unit Exams

Each unit in the thermodynamics course ended with an exam; I called these Comprehension Assessment Tests (CATs), following the practice used at a TBL workshop (*22*). The exams used in my physical chemistry course were similar to the RATs in that they include individual and team sections. They differed in that the individual section of the exam also included a free-response section. The students had approximately an hour to complete the individual exam, which was approximately 1/3 multiple choice and 2/3 free response. When students finished the individual exam, they handed in the free-response portion of their exam and their answer sheet for the multiple-choice portion. They retained the multiple-choice question sheet, gathered in their teams, and once again used IF-AT forms to record the team's answers.

Peer Assessment

After the first unit, the students evaluated their teammates, using the CATME website for this. The evaluation tool on the site asks students about each member of his or her team: Did they come to class prepared? How did they interact with their teammates? How did they contribute to the team's work? How did they keep the team on track? Before the students evaluate each other, the system calibrates them. The students read descriptions of four fictional students, and then rate them using a multilevel rubric. CATME was used to survey the students and deliver the feedback twice each term: after the first exam for formative assessment, and at the end of the term for summative assessment. The final peer assessment was worth five percent of their grade.

Reflections

ACS Data

The final exam for this course is the 2006 Physical Chemistry: Thermodynamics Exam published by the American Chemical Society. Since this exam was given to two earlier cohorts of students who took a lecture version of the course, a comparison is possible. In prior years, the course did not cover some aspects of chemical equilibrium—these topics were taught in the succeeding course. In those years, ACS exam questions dealing with those topics were omitted from the final exam. When designing the TBL course, it was possible to cover all of chemical thermodynamics, because much material was moved out of class and into the Readiness Assurance Process. Thus, for the TBL course, all questions on the ACS exam were included on the final exam. I expected that

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the scores (percentage of correct questions) on the ACS exam would be slightly lower than the traditional course, since the new course covered more material and had some emphasis on soft skills. Instead, the scores *increased,* although not significantly, despite covering much more material, as shown in Table 4.

Table 4. ACS Exam Data

Year	*Method*	*# of questions tested*	*% correct*
2010	Lecture	40/50	68
2011	Lecture	40/50	65
2012	TBL	50/50	70

In retrospect, it is not surprising that TBL works, as it has all the attributes of cooperative learning. The Johnson and Johnson model of cooperative learning has five components: individual accountability, team accountability, in-person group work, development of teamwork skills, and team peer assessment (*23*). TBL incorporates all of these components, as shown in the Table 5.

Table 5. TBL as Cooperative Learning

Cooperative Learning Components	*Team-Based Learning*
individual accountability	iRATs and iCATs
team accountability	tRATs and tCATS
in-person group work	Application exercises, tRATs, and tCATS
development of teamwork skills	Application exercises, tRATs, and tCATS
team peer assessment	CATME

Students have to explain the concepts to each other during tRATs, tCATs, and application activities. Constructing their own explanation is a type of metacognition that leads to deeper understanding (*24*).

Student Comments

The SALG (Student Assessment of Learning Gains) instrument (*25*) was used to survey the students at the end of the term. Several questions asked them how much the various aspects of the course helped them to learn. The results are shown in Figure 4. Note that the majority of students felt that all tests helped their learning, from a moderate to great extent. The majority of the students felt that the screencasts were a great help to their learning.

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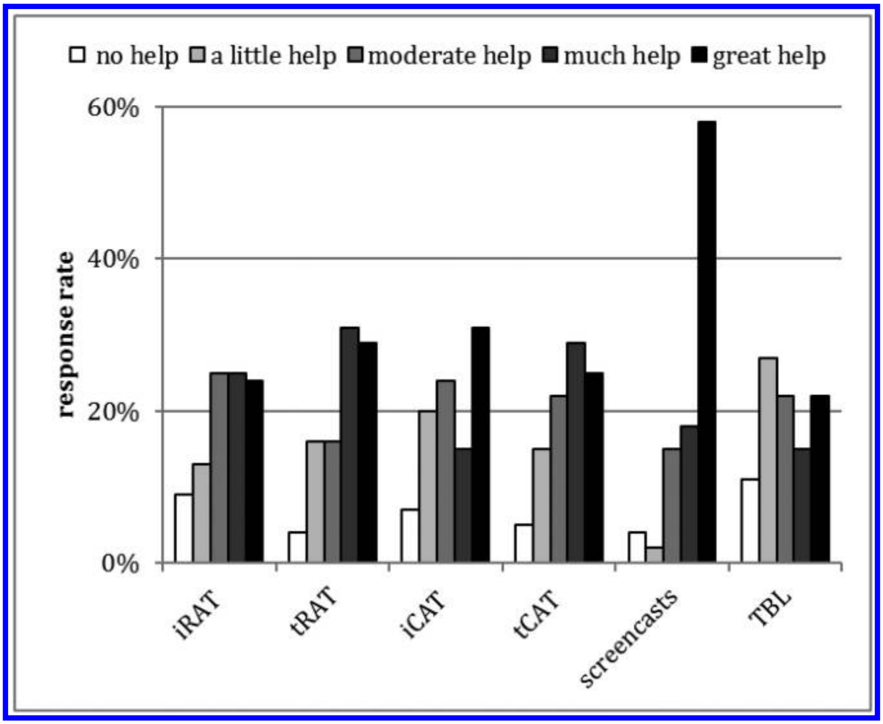

Figure 4. The SALG instrument was used at the end of the course to survey students. Students responded to the question "How much did the following course elements help you in your learning?" In this figure, TBL is an abbreviation for "The instructional approach taken in this class (Team-Based Learning)".

Student response was mixed when they were asked how much the instructional approach taken in this class (TBL) helped their learning. The majority of the students thought that it was of moderate, much, or great help. A few students (11%), however, thought that it was of no help. The students who selected "no help" tended to write very short statements in the free-response text box that accompanied the question. Two examples are "This was the hardest three unit class I've ever take[n]." and "It harmed my learning compared to a traditional classroom environment." The brevity of their remarks makes it difficult to tell why they were unhappy with TBL, or even if TBL was the source of their unhappiness with the course.

In contrast, students who selected "great help" tended to write detailed statements in the free-response text box. Two examples are shown below.

> At first I resented the hands off approach because we struggled, but then I realized the struggling helped us understand the concepts better. At first I think it was a little too hands off, but the right balance was found quickly.

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I'd say although there's room for improvement, I really liked learning p-chem via team-based learning. It wasn't competitive (which is always a possibility when you have teams) and everyone would help each other. Your vague answers to questions, albeit frustrating, do get us to think more and work through the problems with our own critical thinking. Not only this, all the problems were real world hypothetical situations, which made me inherently more interested. The videos were very helpful in mastering the course material (especially conceptual relationships), and I just love your podcast style: thorough, good pace, and gradual increase in complexity.

In general, the students who thought that TBL helped them to learn felt that in the TBL course they had to work harder than they would have in a lecture course, and that they learned more as a consequence.

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Conclusion

Lessons Learned and Current Work

Since offering my first TBL course in 2012, I have continued to teach physical chemistry using TBL. I have made a few changes. The 50-minute, three days a week format was a bit rushed. In addition, the students would take an end-of-unit exam on a Friday, and then take the RAT for the next unit on the following Monday. The students thought that this was not enough time to study. I agreed, and so after the initial course, we switched to an 80-minute, twice a week format. The class is less rushed, and students have almost twice as long to study for the RATs. To ensure that the ratio of time devoted to application activities remained the same, the course was divided into 3 three-week units, rather than 5 two-week units. This structure also allows time in the first week for a general introduction and for team formation.

The students often took longer than expected to complete the application exercises, which sometimes had the result of truncating the discussion at the end of class. Since the summary discussion is such a valuable part of the application exercise, I recommend writing application exercises that are short enough to ensure that there is time for this discussion. In addition, I recommend projecting a countdown timer to help the teams with time management.

All application exercises in my previous courses have been ungraded. In future courses, a small amount of credit will be assigned to teams based on the correctness of the choices the team during the inter-team discussion, in the hope that this will help the teams to work more efficiently.

Recommendations

Instructors considering converting a course to TBL should set aside some time for the conversion, but they should not be daunted by this time investment. Writing TBL application exercises, RAT preparation guides, and recording videos does

take time, but this time is largely a one-time investment. After the first year, the preparation time needed for a TBL course is no more than a traditional lecture course. Many resources for implementing TBL can be found at the website of the Team-Based Learning Collaborative (TBLC) (*26*). In addition, the training workshops run by the TBLC are extremely helpful, to both novice and experienced TBL practitioners.

Final Thoughts

Teaching a TBL class was, for me, more rewarding than a teaching a traditional lecture course. All students were active, and often commented that time went by quickly in the course. In more than a decade of teaching physical chemistry using a traditional lecture style, I never got that comment!

An anecdote is instructive: one morning, in my third year of teaching physical chemistry with TBL, a tractor-trailer accident lengthened my commute by almost two hours. I called the office to leave a note on my classroom door, cancelling my class. However, when I stopped in at the chemistry office, I was informed that the students, after learning class was canceled, had asked if they could stay and work together in their teams! Arriving at my classroom more than half an hour late, I found the students clustered in their teams, working on thermodynamics! Needless to say, I was quite pleased.

TBL works because the discussions in class, within teams and between teams, deepen understanding. Long-time chemistry instructors are experts, in part, because they have heard and refuted many misconceptions. Peer discussions allow students to engage in this same exploration of misconception space, and thus gain expertise.

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Chapter 6

Flipped Teaching in Organic Chemistry Using iPad Devices

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A model for flipped learning in organic chemistry using iPad devices has been developed based on cognitive load theory. All lectures were delivered by video before class using iTunes U, while the textbook has been replaced with the ChemWiki hyper library. The entire class time was then used for active learning. Methods of encouraging student engagement with the videos and classroom active learning sessions are discussed. Student performance was measured across multiple semesters of lecture style courses compared with flipped courses. Students were also surveyed throughout the courses to determine attitudes related to course style and student learning preferences.

Why Flipped Teaching?

Where Did I Start?

Before explaining the pedagogical/andragogical aspects of flipped teaching, there should be some discussion of the decision to flip or not. Prior to incorporating flipped teaching, I would describe my teaching as a mix of lecture and active learning. After explaining new topics, I would typically ask students to apply these concepts to solving a related problem. At the time I felt this amount of problem solving was sufficient because, after all, I understood how to do each problem after only one example. There were several things I wasn't taking into account at this stage; one of the most important is cognitive load, which I discuss in detail in the background. Students were trying to comprehend the meaning of what had just been taught while I was asking them to apply the concepts immediately after hearing the explanations. While there are students that can be successful at this,

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ACS Symposium Series; American Chemical Society: Washington, DC, 2016.

there are many more for whom this could have been causing an impediment to learning.

Engaged Students

I began to notice there could be ways for technology to be used to increase the amount of student engagement in class (ChemDraw® for iPad (*1*)) as well as allow students to review lecture material after class (through recording live lectures and posting to BlackBoard following in-class delivery). Neither of these was designed for improving student preparation before class or reducing cognitive load during class. At this point, while discussing teaching methods at a conference, I was then confronted with some of the classic questions posed by the flipped teaching community.

What is the most difficult activity your students are asked to engage in for your course and when do they do this?

My answer was -- to work organic chemistry problems and outside of class time. The follow up question of "WHY?" left me without an answer better than "that's how we've always done it." This led perfectly to the next question that I had never previously considered.

What is the best use of your face time with your students?

As I began to wrestle with this question, the idea of using class time for discussions and problem solving seemed the best response. I asked myself if students really need me present to take notes on what I say while I am lecturing.

This does not diminish the value of high quality lectures. On the contrary, the lecture is still delivering the primary course content by focusing the information from the textbook and adding explanations as well as dynamic examples of problem solving. This lecture is still as vital a part of the course as for any that I have taught, regardless of delivery format.

What has happened is the students are now required to be active throughout the class time and the instructor is present to guide the students while they are attempting to solve complex organic chemistry problems.

Background

A majority of students report finding the flipped learning model more effective for improving their understanding (*2*). There are several studies reporting on improved learning outcomes in general chemistry including increased performance by the average students compared to the other segments (*3*), overall improvement of scores (*4*, *5*), and decrease in DFW (grades of D, F or withdrawal from the course) rates (*6*). Several studies have reported flipped learning in organic chemistry as well with some various levels of success at showing statistically significant improvements in student achievement. The lack of significance may be related to the low number of participants in one study (*7*) while a second study incorporating small classes suggested that flipped learning can help weaker students successfully complete the course (*8*). When larger enrollment courses were examined, there was a statistically significant reduction

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of failures and withdrawals as well as increased student achievement (*9*). As was shown in most of the flipped learning in chemistry studies, organic chemistry students also reported high satisfaction rates with the inverted format (*10*). There was also a recent review of the published literature related to flipped learning in higher education chemistry which examined course methodology, learning outcomes and potential future directions of this teaching format (*11*).

One intended outcome of flipped teaching via use of pre-class video lectures is an increase in time for active learning during class sessions. This sort of interactive engagement has been shown to be more effective in promoting learning compared to passive student lecture methods (*12–15*). This could be the primary reason that flipped teaching has been effective irrespective of how the students are prepared outside of class (*16*).

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Cognitive Load

Cognitive load theory is based on the assumption of limited working memory and effectively unlimited long-term memory. Working memory can only handle two or three elements during processing. However, people can incorporate several elements together into schemas in long-term memory. When they bring one of these schemas into short-term memory, they can effectively use many more elements to solve a given problem. This allows solving of complex problems that require many elements to engage the problem. Many organic chemistry problems require this type of problem solving, and with new problem types students often do not have schemas for solving them. When a topic is introduced in class and students are immediately asked to attempt to solve problems using this new information (e.g., these new elements), the students have not been able to form a schema for this material yet and many may fail at solving the problem (*17*).

In addition, there is an intrinsic load imposed on working memory for every activity based on the complexity of the related material. Higher complexity material imposes a heavier cognitive load. Each student has a certain capacity for the amount of cognitive load he or she can handle before reaching a state of overload. For a field such as organic chemistry, assimilation of material can quite easily lead to this type of cognitive overload. Chunking of information into schemas before class meetings can help students to be better able to engage with problem solving during class time without reaching a state of cognitive overload (*18*).

The pre-class videos are designed to reduce cognitive load during class through delivery of course content and first interaction with course material (where students are learning how to identify structures, examine reactions and recognize patterns) before class. This allows the students to create a model of the information by pre-training, so that when they arrive at class and are asked to work problems, they are not trying to use the model at the same time they are trying to create the model (*19*). This type of previewing of materials has been shown to be effective whether delivered in person (*20*) or electronically (*21*). The most common measure of effectiveness has been in closing gaps in chemistry preparation by improving performance of less prepared students, since this group

is less likely to already have developed thorough working models for the course content.

The complexity of problem solving in chemistry requires higher order thinking skills and these can have a tendency to exceed working memory when students are asked to apply concepts at the same time these concepts are first presented. These higher order activities include comparing and contrasting, differentiating between alternatives, constructing a synthetic scheme and combining several concepts to solve integrated problems. By shifting the focus of these component models to home study time, we can address and support more complex problems in class without overloading working memory, as well as to build on more complex issues, which is the foundation for chemistry.

Methods

Course Information

These methods have all been incorporated into Organic Chemistry I and II at the University of Illinois Springfield during 2013-2014 and 2014-2015 academic years. The enrollments in the courses vary from 20 during Summer to 60 during Fall and Spring semesters. The students are a mixture of chemistry, biology and clinical lab science majors. The lecture is a separate course from the laboratory. Class meetings are two times per week for 1 hour 15 minutes during Fall and Spring semesters (16 week terms) and two times per week for 2 hours 30 minutes during an 8-week Summer term.

Surveys

Students were surveyed at various times during each course. The surveys were delivered in several ways. There were anonymous surveys delivered via Qualtrics (*22*). The majority of questions were presented using 5-point Likert scales. There were several different groupings of questions including the following response choices:

a.				
Didn't learn Anything	Learned a little	Moderate learning	Learned a lot	Learned the most
b.				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Open-ended questions were included in which students were encouraged to discuss their experiences with flipped learning and many of the apps used during the course. There were also surveys that allowed for comparison of student attitudes with course performance.

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Course Components

iPad

The primary tool I use for flipping my class is the iPad. There have been several articles that have explored the use of the iPad in teaching chemistry. These range from the instructor using iPad to augment their teaching (*23–26*) to single applications used by students (*27–29*) to more fully integrated deployment (*30*, *31*). iPad devices have been a required course component for all of my flipped courses and were chosen primarily for specific apps that were available only for iPad or iOS, including ChemDraw® (*1*), iSpartan (*32*) and iTunes U (*33*). In addition to these chemistry apps, there are many general uses that have been incorporated

- Camera – taking pictures and video
- Explain Everything (*34*), iMovie (*35*) and Adobe Voice (*36*) – which allow students to create video explanations
- Notability (*37*) – for note taking. This has a couple of advantages over paper notebooks since students can easily copy and paste when drawing repeated structures and it is less likely that a student will misplace his or her course notebook, since it is stored on the iPad
- Socrative Student (*38*) and Socrative Teacher (*39*) – quiz program

The iPad has shown itself to be a powerful tool in the classroom, laboratory and for studying outside of class. All students having the same device has made incorporation of new components to the course much easier.

Screencasts

The lecture material for class is delivered via a set of lecture videos that were pre-recorded and hosted on iTunes U. iTunes U was chosen as the hosting site for this course as it allowed incorporation of all course materials in one place, with the videos, links to each topic within the text, practice quizzes, and course assignments where the students can turn in their materials and carry on private dialogue with the instructor. This provided more capabilities than with either YouTube or BlackBoard (two of the other commonly used options). These videos were recorded and edited using Camtasia Studio for Windows (*40*) and iMovie and consist of screencasts that were written on a Wacom Bamboo tablet using AutoDesk Sketchbook Express 6 (*41*) whiteboard software and audio captured with a Blue Snowball microphone. The screencasts are whiteboard only, meaning that I do not visually appear in them, as seen in Figure 1.

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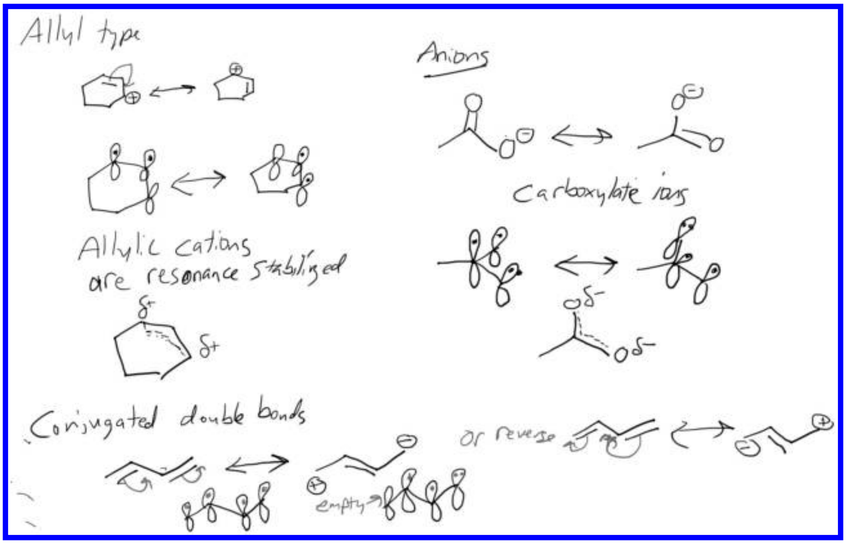

Figure 1. Example image of a screencast.

The lecture material for Organic Chemistry 1 consists of 70 videos that total 8 hours 46 minutes with an average length of 7:31. Organic Chemistry II is made up of 59 videos totaling 7 hours. The videos were edited to reduce "dead time" while drawing structures or writing out longer sentences. This was typically achieved by increasing the video speed to 3x normal speed while the sound was muted during these segments. Despite the large time investment for creating these videos, I consider it worthwhile as the majority of the course content of organic chemistry is the same from year to year. I have updated several of the videos and intend to continue do so as the course material changes in the future, but I do not expect to have to re-record the entire course at any point. This is similar to how I used to view course lecture notes. The first time teaching a new class takes a lot of course note preparation, but subsequent times through the course would only warrant small modifications with the occasional complete chapter re-write.

Quizzes

Several attempts have been made to encourage students to engage with the video materials in order to prepare them for classroom discussions and problem solving sessions. During the first semester of flipping, quiz questions were embedded into the videos. These forced students to periodically pause and answer

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a question before the video would continue. This caused some students to rush through the videos to get to the questions. Subsequently a method was devised that I believe encourages students to watch the videos with the goal of increased understanding. For the past year, quizzes have been given at the beginning of each class meeting based on the material from the assigned videos. To encourage the students to actively engage with the videos, students are allowed to use their notes on the quizzes. The majority of students, 88% (N=48) agreed or strongly agreed with a 5 point Likert scale statement "The daily quizzes encouraged me to take good notes."

During the first semester that the in-class quizzes replaced the quizzes embedded within the videos, the rate of student viewership remained approximately steady with 92.9% watching each video with embedded quizzes and 95.9% with in-class quizzes (these were measures of students that viewed any portion of the video as there was no mechanism available to gauge the length of time spent watching each video). This was one of the first positive signs that hinted toward students being more aware of their personal responsibility for their learning, since there was no direct consequence for missing a lecture video, but an indirect consequence of not learning the material to be prepared for the ensuing quiz.

These in-class quizzes are all submitted using the student iPad. There are three main apps used to administer the quizzes. The selection of app depends on the type of question being asked.

Socrative

Socrative (by Mastery Connect) is an instant response tool that can be used via a web browser or as a stand-alone app on mobile devices. The web version was used on a personal computer to create questions. This was typically done by drawing out the question and multiple choice answers on ChemDraw® and exporting the resulting images. These images were imported into quiz questions within Socrative. The Socrative Teacher app was then used to deliver quizzes during class and monitor student responses. The Socrative Student iPad app was used by the students for this course, as shown in Figure 2. Though there are limited question types (multiple choice, true-false and open answer – which allows students to freely type a response) the advantage to using Socrative is that the instructor gets real-time feedback regarding who has correct answers as well as a percentage correct for each question, as shown in Figure 3. This was used for formative assessment that would guide which concepts required more class time. When the quiz time was complete and all student answers were submitted, the summary of student answers showed the number of correct answers for each student. Each student answer was also highlighted green if correct or pink if the answer was incorrect, which allowed for a quick visual analysis of the class results.

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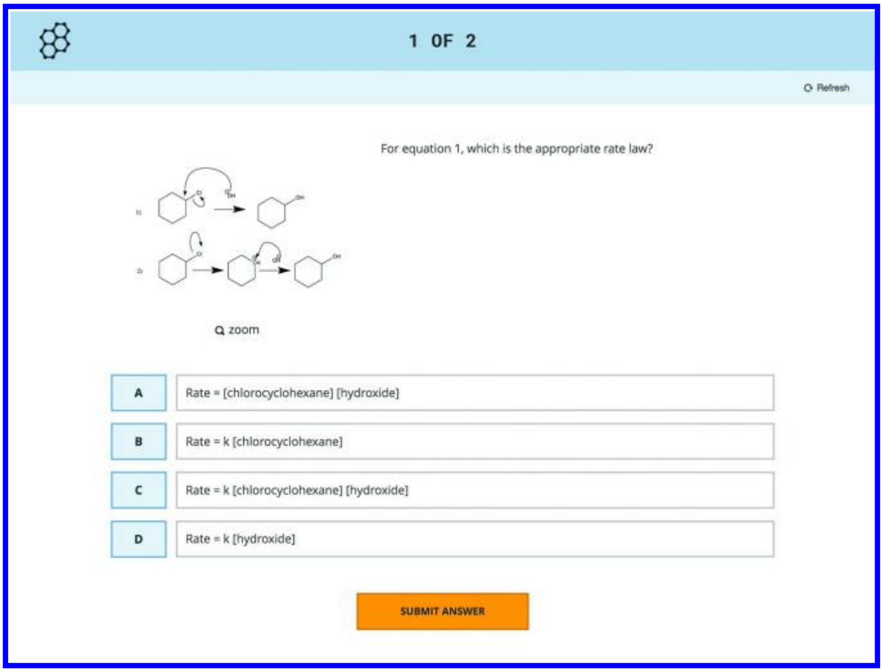

Figure 2. Socrative student example of a quiz question. (Reproduced with permission from Ref. (38). Copyright 2016 MasteryConnect.)

ChemDraw® Mobile Software Application

PerkinElmer's ChemDraw® software mobile version for use with iPad devices has been used successfully in my class since it was released in 2013 (*29*). Questions where students need to draw chemical structures, reactions and mechanisms were all asked using this app with an example shown in Figure 4. Several different methods of student submission of these quizzes have been used. The ChemDraw® app has an embedded information exchange protocol called Flick-to-Share that can be used to send files of chemical structures drawn using the ChemDraw® app between individuals or groups. When this feature is used, the instructor can access a web page that lists all of the individual submissions from students, including student email address and time of the response. Each answer can then be opened in the ChemDraw® software on a personal computer (or the mobile app on an iPad). While teaching a smaller summer class, students were asked to submit their responses generated using the ChemDraw® software app via email as a pdf. This could be accomplished directly from the app by using the share via email function. With the introduction of iTunes U 3.0, these files could be uploaded directly into an iTunes U private course. This has the added advantage of an area for instructor feedback on each item submitted and for the student to respond directly to the instructor. In addition, if the work submitted

is a pdf, the instructor can mark directly on the quiz and this feedback is shared solely between the student and instructor. Use of iTunes U has greatly increased dialogue between the students and instructor on assignments and quizzes.

Notability

The most flexible of the tools used for student quiz responses was Notability (by Ginger Labs), which is a note-taking and annotation app. Use of Notability permitted questions where students were asked to draw responses just as they would on paper, as shown in Figure 5. This has been especially useful to have students draw graphs and energy diagrams, though it was used for some mechanisms, structures and orbital drawing as well. These responses can also be shared directly from Notability to iTunes U as a pdf. This allowed the same grading and interaction described earlier for the documents created using ChemDraw®.

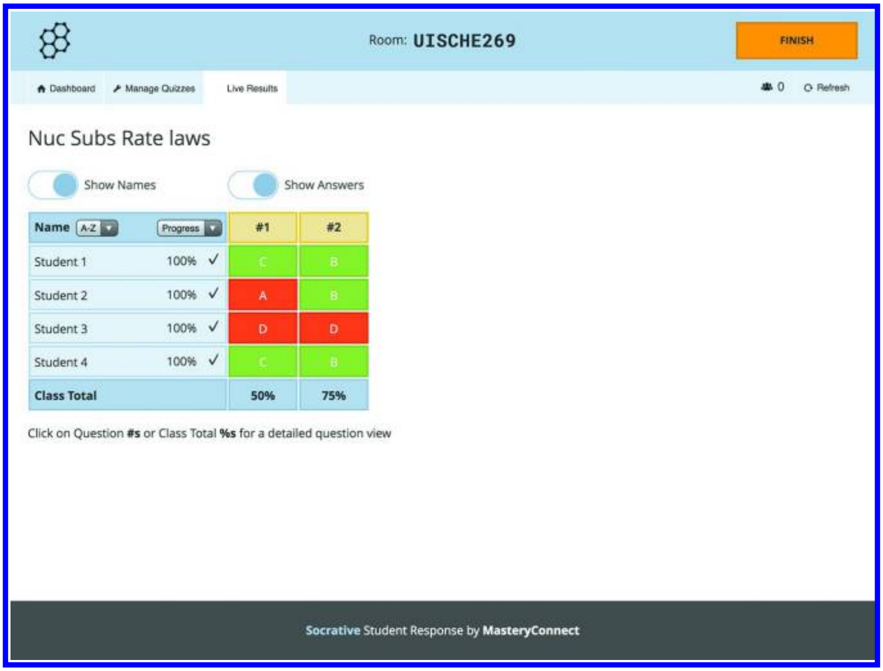

Figure 3. Socrative Teacher example showing correct answers in green and incorrect answers in red. (Reproduced with permission from Ref. (39). Copyright 2016 MasteryConnect.)

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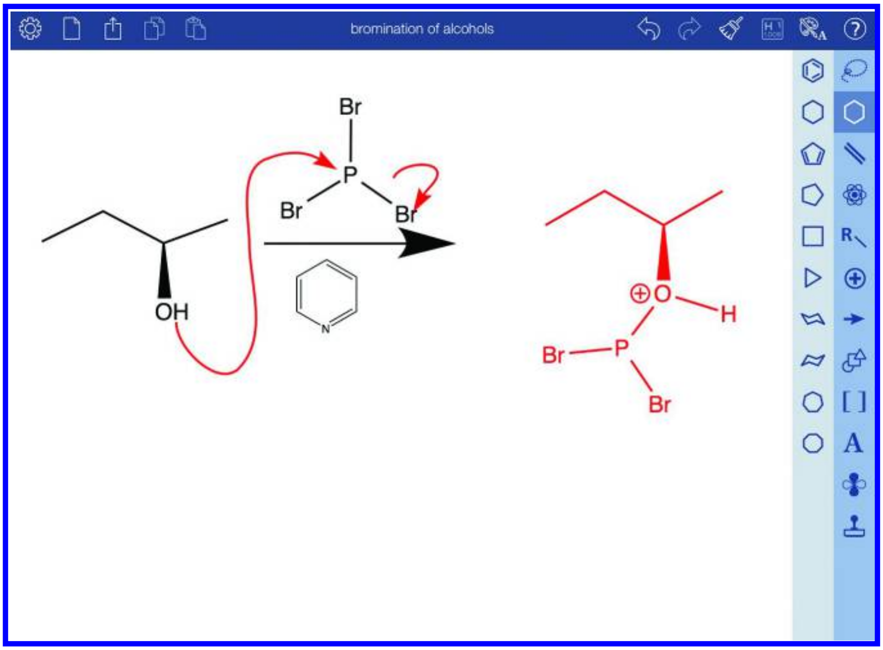

Figure 4. Student quiz partial solution solved using ChemDraw® (1). Students provided the arrows and product. (Contains PerkinElmer, Inc. copyrighted material. Printed with permission. All Rights Reserved.)

In-Class Problem Solving

The main purpose of the aforementioned screencasts was to repurpose the class time away from a more passive lecture to more active problem-solving sessions. For this to work, the students need to be prepared when they arrive at class. Self-efficacy can strongly aid this process, as students that can see there is a benefit to doing the assigned work are more likely to engage in these practices. When surveyed, 92% of students (N=48) in organic chemistry agreed or strongly agreed with a 5 point Likert scale statement "Watching the videos before class helped me in working the in class problems."

The majority of class time was used for active problem solving. Problems were posted individually or several at a time and students were asked to work on them. The methods would vary within each class period and between class periods. Methods included:

- Problems that students were asked to solve on their own, then explain to a neighbor. These were always given in pairs of problems so with the second problem, students were asked to switch roles between explainer and listener.

- Students were encouraged to discuss their answers as they worked through the problems with the students around them.
- Several problems would be posted on the boards in the classroom and groups of 2-3 students were asked to work out the answers together and then come to the board and choose a problem to write out their combined solution.

One common theme throughout the problem sessions is having students explain their answers to others, which has been shown to increase meaningful learning across varying age groups and fields of study (*42*, *43*). All of these methods were followed by detailed discussion of the solution of each problem by the instructor. When there were student answers, the instructor would point out common misconceptions while reminding students that mistakes were desirable as they actually help the class as a whole learn better. There was never a worksheet passed out with problems on them, since in previous experience this would signal students that they had a lot of time available and therefore did not need to stay on task. Instead, all of these methods incorporate an immediacy that the students will be asked to somehow discuss the problems.

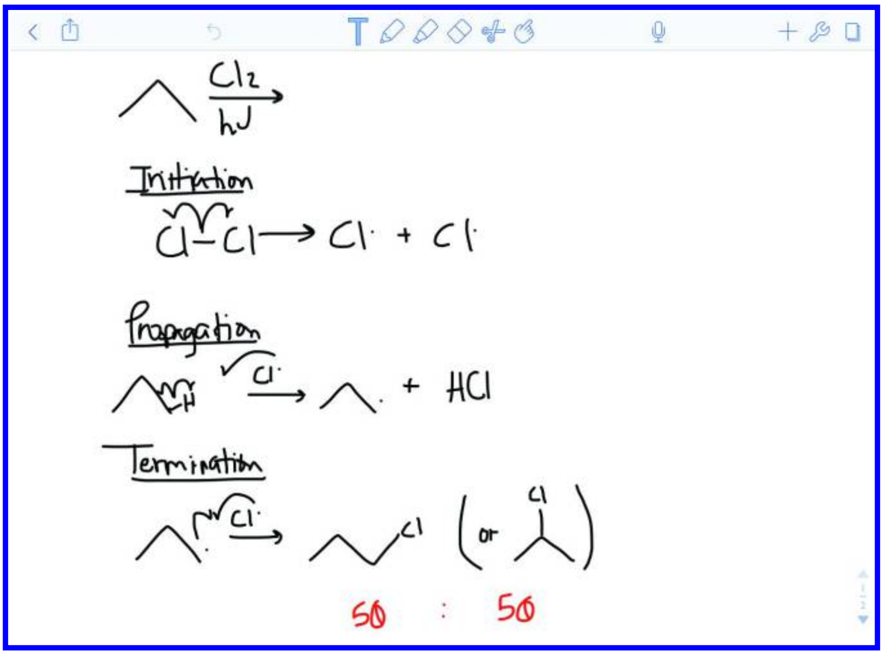

Figure 5. Example of a student solution to an in class quiz, using Notability. The first line shows the reaction that was given to the students to write out a mechanism. (Reproduced with permission from Ref. (37). Copyright 2016 Ginger Labs.)

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ChemWiki

Beginning in the summer of 2015, the traditional textbook was replaced with the ChemWiki (*44*) (a hyperlinked library with approximately 15,000 pages of chemistry content). This was integrated directly into iTunes U with links from each course topic to the relevant page within the course in the ChemWiki as in Figure 6.

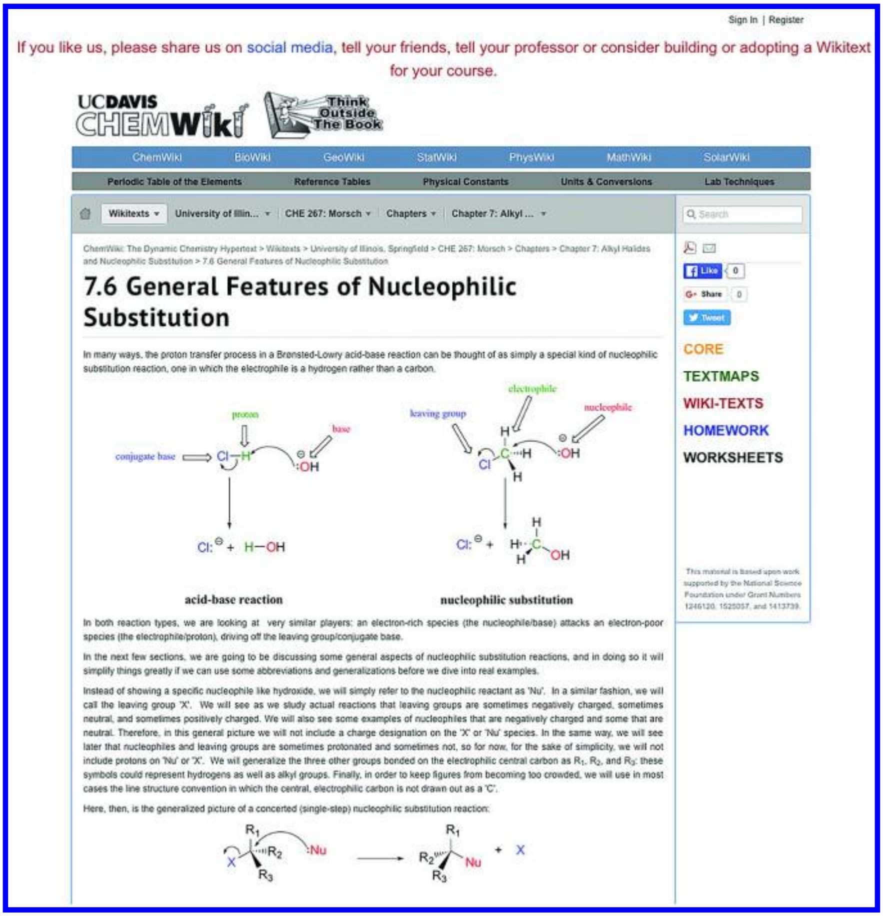

Figure 6. Sample ChemWiki page. Graphic created by Tim Soderberg, (Reproduced with permission from Ref. (44). Copyright 2016 ChemWiki.)

The ChemWiki has been shown to be equally as effective as textbooks based on student learning in General Chemistry courses tested with 926 students at the University of California Davis (*45*). No similar study has yet been published in organic chemistry. I have limited data in this area but plan to explore this question once the ChemWiki has been used for more courses. In addition to giving students free access to the same type of information that is contained in traditional textbooks, teaching students to use the ChemWiki encourages

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digital literacy. Digital literacy can be defined as the ability to locate, organize, understand, evaluate and analyze information using digital technology. This is already a vital skill for all educated citizens and we need to explicitly incorporate more digital literacy into higher education. With the great increase in people looking primarily to web resources to find information, it will clearly benefit the students to guide them to high quality online information sources.

iTunes U and Course Organization

The entire course content is organized on iTunes U, with all deadlines for the semester planned in advance and links to each video lecture and ChemWiki page as shown in Figure 7 (The video link is labeled "Watch Section 9.12", while the ChemWiki link is labeled with the section title "Conversion of Alcohols…"). This includes due dates for watching each of the videos, reading the chapter and working out the sample quizzes. There were two main goals for designing the course in this way. First, it organized a rather large set of new apps and digital content for students that could be otherwise overwhelming. This increased course organization led to 66% of students agreeing or strongly agreeing with the statement from a 5 point Likert scale "iTunes U helped me with organization" and only 8% disagreeing or strongly disagreeing with the statement.

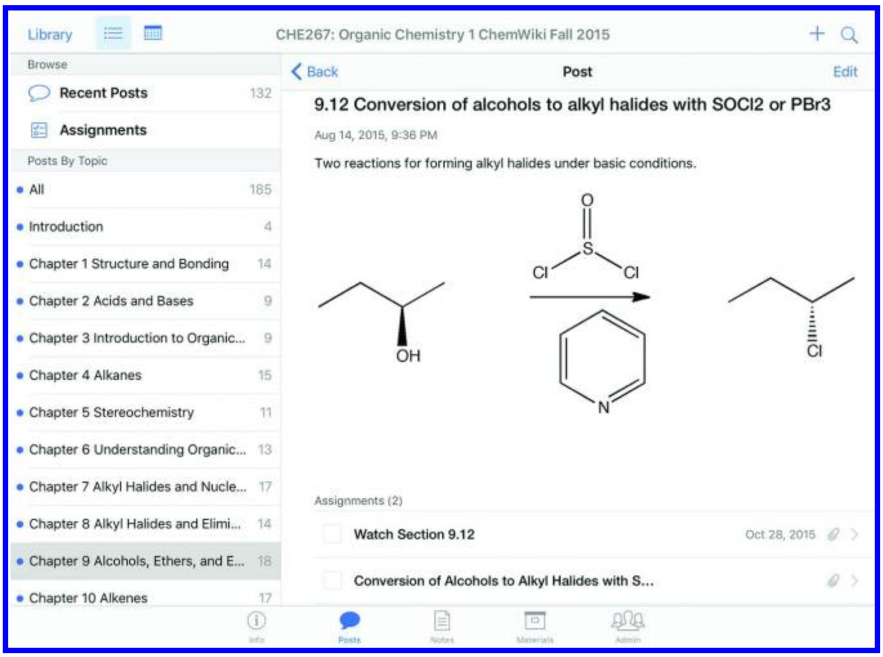

Figure 7. iTunes U organization. (Screen shot reprinted with permission from Apple Inc. (33))

Muzyka and Luker; The Flipped Classroom Volume 1: Background and Challenges
ACS Symposium Series; American Chemical Society: Washington, DC, 2016.

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Sample quizzes are provided for each chapter with a blank copy and a solved copy (with longer chapters having multiple quizzes). Students are then encouraged to attempt the quizzes without using any study materials. These are designed for students to work out the problems, while studying, to gauge their own understanding level. One of the most surprising student responses to my flipped courses has been the number of students that have requested more problems to work through on their own. There are no points assigned to these problems, so the most plausible explanation for these requests is that students are realizing what work needs to be done to better understand the material. This is a second and stronger sign of personal responsibility for learning by the students that is an important desired outcome of university education.

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Data

Attendance

When I first heard about flipped teaching, a couple years prior to adopting, I was skeptical about whether students would attend a class if all the lecture material were available for them outside of the scheduled meeting time. Would students still find any reason to attend lecture? The data on my previous lecture classes is limited, as attendance was not taken for most courses; however, two semesters had daily activities that allowed for attendance numbers for those courses to be compared to the flipped courses that have been taught subsequently. The average attendance in the lecture courses (91.8%) compared to flipped courses (90.3%) revealed no significant difference. This clearly didn't show the type of attendance drop off that was feared. Instead, students when surveyed have consistently rated "In-class problem solving" as the most useful part of the course for learning organic chemistry (from a series of course components given a 5 point Likert scale where 5 is "Learned the most", average of 4.48 out of 5). This was rated higher than any other portion of the course with "watching the course lecture videos" the second highest rated portion as shown in Figure 8. Students were allowed to rate the importance of each item independently (they were not forced to rank them in order). This high student valuation of the class time being used for problem solving helps explain the strong attendance numbers. Also, when quizzes were proctored during each flipped class, attendance showed a statistically significant increase to 92.0% compared to 88.8% for flipped classes without in-class quizzes ($t(81)=2.30$, $p=0.02$).

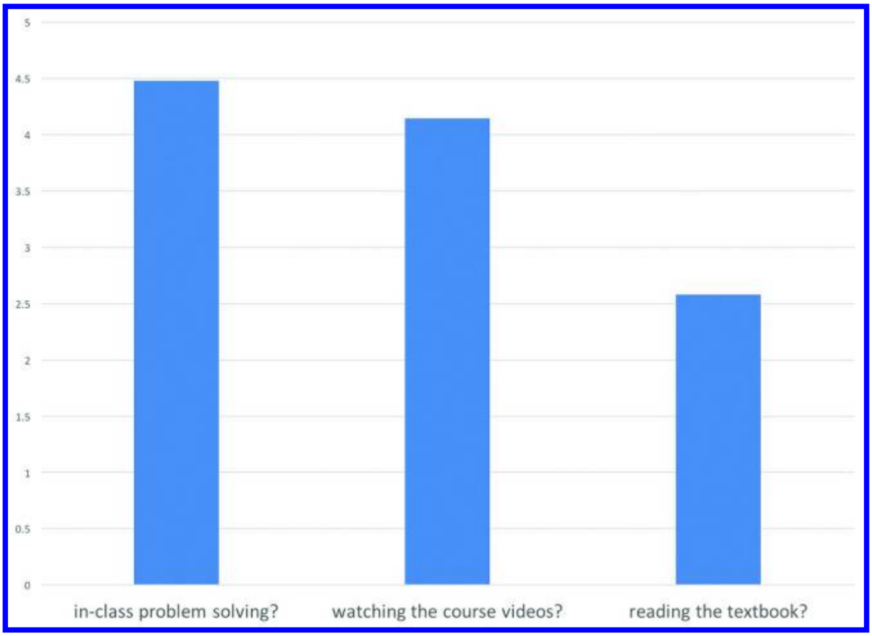

Figure 8. Average student responses over 3 terms to the question "What were the most useful parts of the course for learning organic chemistry" (5=learned the most and 1=didn't learn anything).

Student Assessments

To analyze how student performance is affected by engaging in flipped learning, final exam grades have been compared across 4 years in Figure 9. This includes 3 lecture sections (first three columns on the left) and four flipped sections (last 4 columns on the right) of the course. Final exam grades were selected to compare, since quizzes and assignments differed by course. These final exams comprehensively cover all material from the semester and can serve as a reasonable measure of overall learning in the course. Additionally, the overall content of the exam varies little across the years included in the study. An independent-samples t-test was conducted to compare the final exam scores for flipped and lecture classes. There was no significant difference in the scores for flipped (Mean=161, SD=32.1) and lecture (Mean=148, SD=34.5; $t(df=110)=1.75$, $p=0.08$).

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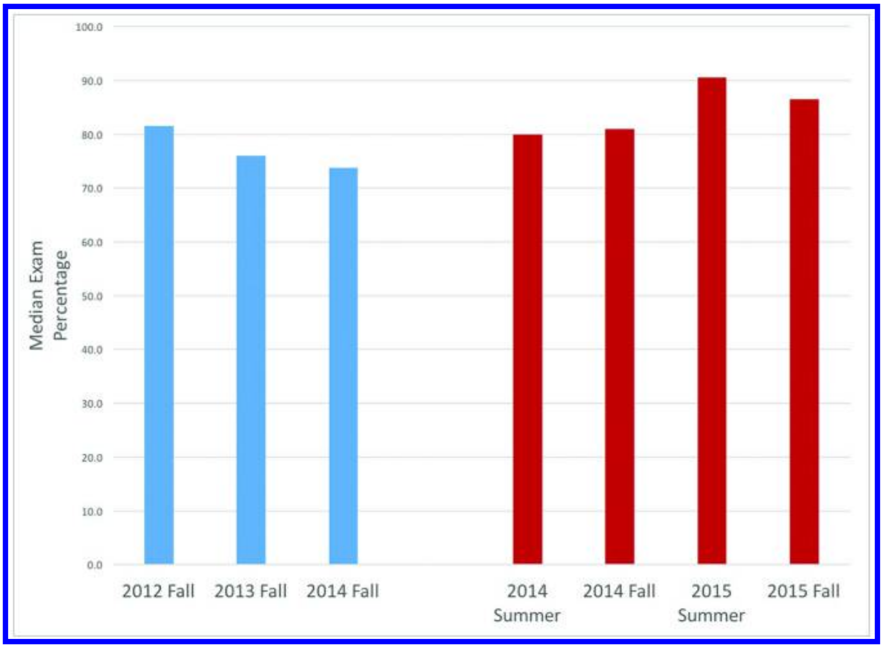

Figure 9. Median final exam percentages for Organic Chemistry I courses at the University of Illinois Springfield (first three columns traditional lecture sections, final four columns flipped sections).

A chi-square test was performed to determine whether final exam grade distributions were equal in flipped and lecture classes. They were not equally distributed, χ^2 (4, N=241) = 13.14, p = 0.05. Students in the flipped class were more likely to get A and B grades on the final exam and much less likely to get D's as shown in Figure 10. (Exams were all graded where 90%+ = A, 80-89% = B, 70-79% = C, 60-69% =D and below 60% = F). This shift in graades is an outcome of reducing cognitive load during class. Typical lecture classroom activities would exceed many students' ability to see/hear a concept, incorporate it into their understanding and apply it all within one course meeting. By shifting the initial interaction with the concept, it allows the students to already have a working idea of the concept before being asked to apply it during class.

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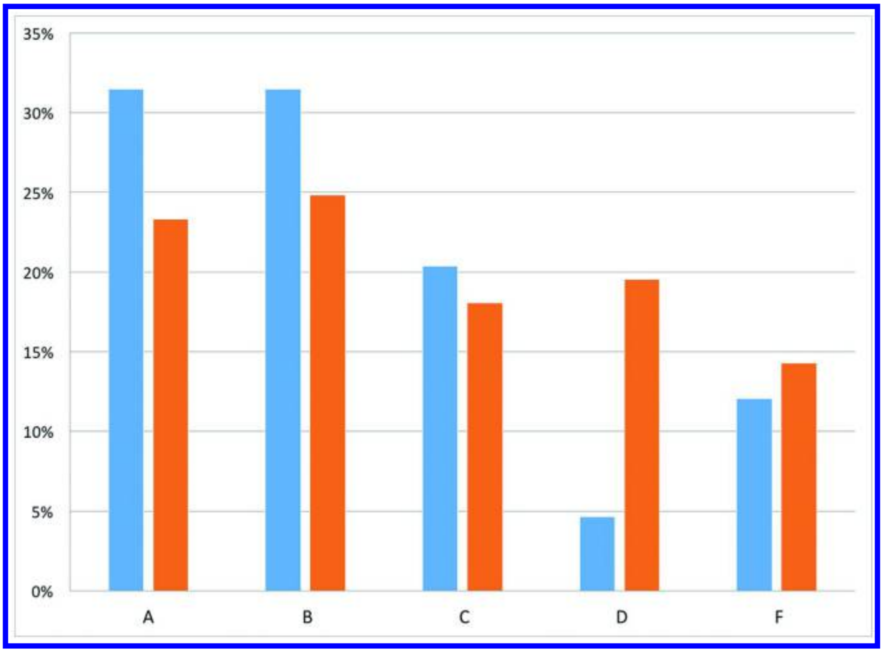

Figure 10. Final exam grade distribution for Organic Chemistry 1 courses at the University of Illinois Springfield, 2012-2015. (blue/left columns = flipped sections and orange/right columns = lecture sections).

Student Attitudes

Students in the flipped courses were asked to reflect on the courses at several times throughout each class. Both quantitative and qualitative questions were asked to assess the perceived value of class components and to probe student attitudes using 5-point Likert scales. One student complaint reported by some faculty members who have tried flipped teaching is that more study time is required (*7*). Only 38% of students surveyed agreed or strongly agreed that "Flipped learning took more time than typical lecture classes."

Another facet of flipped learning that has been mentioned previously is students' taking personal responsibility for their own learning. When surveyed, 81% of students either agreed or strongly agreed that "Flipped learning helped me to be in control of my own learning".

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Conclusions

Flipped learning is a growing teaching methodology in organic chemistry that is being used to increase active learning in the classroom. It has the potential to reduce cognitive load and thereby increase understanding and course performance, particularly for moderate to lower achieving students. I have been engaging in a novel method of flipped learning through the use of iPad tablet technology during class and outside of class in an attempt to reduce cognitive load during class and improve student performance. Lecture videos viewed before class, along with encouraged note taking, replace the previous in-class lectures. Quizzes given at the beginning of each class period encourage the students to engage with the video lectures. Active problem solving during nearly all class time is posited as the most valuable aspect of the flipped teaching. iTunes U and the ChemWiki have been incorporated into this flipped learning model, increasing clarity of course organization while giving students exposure to open educational resources. Through all these adaptations students are asked to engage with, both student attitudes and performance have been positive to the new class format.

There are still many factors to be explored related to flipped teaching including whether videos are more effective than other methods of pre-lecture preparation and what types of active learning activities during class are most effective. The field would also benefit from analysis of types of learners that have the most success with flipped learning. Many of us have seen the potential for flipped learning and we need to continue to assess this learning model to determine best practices for robust student learning.

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Chapter 7

How a Flipped Classroom Promotes Sophisticated Epistemology: Example from a Large Analytical Chemistry Course

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One goal in undergraduate science education is to facilitate skills that help students become equipped to participate in research. Although not all students will go on to become researchers, the skills that are key to independent research are essential for any mature learner. Participating in research necessarily requires one be to be critical, solve problems independently as well as collaboratively, while having a deep understanding of how knowledge is constructed. Moreover, one must see oneself as being able to contribute to the current body of knowledge. Moving a student from a novice learner to a mature learner capable of conducting research involves a shift or transformation in epistemology. Beliefs about knowledge and how knowledge is created are referred to as a individual's personal epistemology. In general, university students often are in a stage where they view knowledge in terms of simple right or wrong answers, as certain and finite, and they look towards an external authority such as the instructor as the holder of knowledge. Students with these views may struggle with activities like independent research. In this chapter, we discuss how the flipped classroom approach can promote transformations in students' personal epistemologies. We provide a summary of the educational theory that underlies the flipped classroom approach as well as a summary of

epistemology research in higher education before providing an example of a flipped classroom approach in a large Analytical Chemistry course. In the exemplar, there were indications of sophisticated epistemology from students based on in-class observations by the instructor, student-generated work and from student responses to the end of term survey. These incidents indicate that flipped classroom approaches similar to the exemplar have the potential and capacity to facilitate sophisticated views of the source, simplicity and tentativeness of knowledge.

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Introduction

Important goals in undergraduate science education are to promote critical thinking, independent problem solving, teamwork, a deeper understanding of the scientific knowledge construction process and the self-confidence to contribute to the current body of knowledge (*1–4*). In other words, undergraduate science students should be equipped to participate in research, which necessarily requires one to be critical, solve problems independently as well as collaboratively, while having a deep understanding of how knowledge is constructed and to see oneself as being able to contribute to the current body of knowledge (*5*). Moving a student from a novice learner to a mature learner capable of doing research involves a shift or transformation in epistemology. Beliefs about what constitutes knowledge and how knowledge is constructed refer to a person's epistemology (*6*). In general, university students are often in a stage where they view knowledge in terms of simple right or wrong answers, as certain and finite, and they look towards an external authority such as the instructor as the holder of knowledge (*7–10*). For example, students with a naïve epistemology may view scientific knowledge as simple and consisting of proven facts, rather than as complex and based on evidence and theory (*7*). Students tend to naively believe that most questions have already been answered so there is no place for them to add to the existing knowledge, and they may also believe that scientific knowledge does not change since it is based on proven facts (*7*). Students who see their instructors or professors as the source of knowledge often struggle with activities that require independent research where they decide on what knowledge is worth reporting, hence themselves becoming the source of knowledge (*11*). In contrast, a researcher would have more sophisticated epistemological views. Sophisticated epistemology arises from a deep understanding of the nature of knowledge and its construction. Researchers are necessarily critical. Critical thinking involves the use of reason to make decisions and not simply accepting knowledge as a set of rules or facts without meaningful consideration (*12*). Thus, critical thinking involves shifting away from a reliance on only the external authority and a view that knowledge is simple to a reliance upon one's own ability to reason and a view that knowledge is complex (*13*). Researchers view

knowledge as tentative and expanding because they have a better understanding of how knowledge is constructed and the limitations of knowledge; the limits of a model or an analytical technique are examples. They are studying questions that attempt to improve upon the limitations so they see themselves as contributors to existing knowledge. Thus, important goals in undergraduate education involve a transformation in how students are taught to view the source, simplicity and tentativeness of knowledge (*4*).

How can we promote epistemological transformations in students and help them to become better equipped to participate in research? It has been shown that an effective way is to provide undergraduate research opportunities (*14–16*). Also shown to be effective is using specific techniques in the classroom (*3*, *17*, *18*). In this paper, we will discuss how the flipped classroom approach can promote transformations in student's personal epistemologies. The flipped classroom approach involves taking events that have "traditionally taken place inside the classroom now take place outside the classroom and vice versa" (p. 32) (*19*). Instead of receiving information in class and doing homework outside of class, students receive information before coming to class and tackle what were previously challenging homework problems, in class (*20*). In most of the current literature, flipped classroom has started to mean something more specific (*21*). A flipped classroom may involve online video lectures that students watch before coming to class, perhaps supplemented with readings and exercises. Students would be held accountable for these pre-class activities though quizzes or other marked assignments. In class, there would be a peer-learning component. One of the concerns in teaching is that when students do homework problems, they do not connect the underlying concepts with the lecture material but instead find the patterns that can be imitated (*20*). If homework-type problems are done in class, this approach will allow the opportunity for the instructor to guide students in assigning meaning. In the following sections, we provide a summary of the educational theory that underlies the flipped classroom approach as well as a summary of epistemology research in higher education before providing an example of a flipped classroom approach in an Analytical Chemistry course. Lastly, we will discuss the ways the exemplar facilitated potential transformation of students' epistemologies.

Theoretical Perspective: Constructivism

Undergraduate science courses that rely on only lecturing and using exams with right or wrong answers to measure understanding of content are rooted in a traditional theoretical perspective. In this perspective, education focusses on content (what every educated person needs to know) rather than process (*22*). This perspective is rooted in the broader philosophy that reality is external to the individual and there is a single truth (positivism). A flipped classroom practice is different from a traditional lecture because it is grounded in the constructivist framework. Constructivism is a theoretical perspective that considers new

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knowledge to be created by actively constructing ideas and generating meaning based on prior knowledge (*22*). This perspective is rooted in the broader ontology that there is not an independent pre-existing reality outside the mind of the knower (*23*). Constructivism is associated with Jean Piaget and Lev Vygotsky. Piaget asserts that children and adults use mental patterns (schemes) to guide behavior or cognition, and interpret new experiences or material in relation to existing schemes (*24*). However, for new material to be assimilated, it must first fit an existing scheme. When a learner encounters situations in which his/her existing schemes cannot explain new information or experiences, existing schemes are changed/transformed, a process that Piaget calls accommodation. The condition leading to accommodation is known as disequilibrium; that is, the state encountered by a learner in which new information does not fit an existing scheme (*24*).

Vygotsky also recognized prior knowledge as an important factor in learning. He categorized learning into two types: 1) everyday learning and 2) learning that occurs in a formal setting (*24*). When a student learns in a formal setting, he/she eventually come to see how his/her everyday experiences fits into the system he/she has been taught and vice versa. Vygotsky (1978) viewed learning as a social process, which is key to his theory. Dialogue with the teacher and peers plays a crucial role in learning to bridge the gap between the two categories of learning (*24*).

The flipped classroom is an instructional practice that is inspired by constructivism and the theories of Jean Piaget and Lev Vygotsky. A flipped classroom approach follows Piaget's theories because the focus is on student's prior understanding and misconceptions of the pre-class material. Students are given material to read and/or watch in an online video before class where they gain a superficial understanding of the course content. In the flipped classroom, lower levels of Bloom's taxonomy, such as definitions and basic content, are facilitated outside of class (*25*). Student understanding and misconceptions are brought to the surface with challenging problems in class that force students into disequilibrium while the instructor is there to guide the students towards accommodation. Typically, in the classroom, students are asked to think of an answer on their own to a challenging problem and then discuss the solutions with their peers. This is followed by a whole class discussion led by the instructor (*25*, *26*). In this method, students rely on their understanding of the pre-class material to identify the correct answer, then hopefully identify misconceptions through the discussion with peers and the instructor. A flipped classroom approach applies Vygotsky's theories since most flipped classroom approaches rely on peer-based learning in the classroom (*25*). A flipped classroom approach is a way of planning and teaching content differently from the traditional method of teaching. Knowledge is being constructed by the students assigning meaning to the concepts highlighted in the problems which are based on what they learned before coming to class. During class, students can experience disequilibrium but the instructor and peers are present to facilitate the formation of a new mental scheme in the student. What is important about a flipped classroom is that the student is not outside the classroom during disequilibrium where, without a guide, he/she could develop incorrect schemes or misconceptions.

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Epistemology in Higher Education

Personal epistemology has its origins in cognitive psychology (*27*). William Perry (1970) and subsequent researchers view personal epistemology as a cognitive development process that proceeds in a patterned, developmental sequence (*13*, *28–30*). In this approach, students move from a naïve position of a dualistic or absolutist view of knowledge where students identified knowledge as simply wrong or right. The higher positions involve students acknowledging that there is uncertainty in knowledge and there are multiple perspectives until finally, the students see themselves as contributors to knowledge and the role of evidence and justification of knowledge is recognized (*27*). A second model is viewing personal epistemology as a multi-dimensional system of beliefs (*31*, *32*). This multi-dimensional model began with Schommer's (1990) study and has been developed further by Hofer (2000). Instead of a developmental sequence, Schommer's theory characterized epistemological beliefs as a set of *independent* dimensions. In multi-dimensional models, an individual can be in a naïve stage in a certain dimension of knowledge but more developed in a different dimension of knowledge. In both Hofer's and Schommer-Aikins' models, the dimensions can be categorized into two themes: the nature of knowledge (what knowledge is) and the nature of the process of knowledge (how one comes to know) (*31*). For example, in Hofer's (2000) model, there are 4 dimensions: certainty of knowledge, simplicity of knowledge (both of these dimensions fall under the category of the nature of knowledge), source of knowledge and justification of knowing (the last two dimensions fall under the category of the process of knowledge). Examples of epistemological beliefs would be: knowledge is fixed and unchanging; knowledge is simple and an accumulation of facts; knowledge resides in an external authority; knowledge is evaluated through the rules of inquiry (*31*).

Exemplar Application of a Flipped Classroom Approach in a Large Analytical Chemistry Course

The following is a description of a flipped classroom approach used in a 2^{nd} year Analytical Chemistry course in 2012-2014. The flipped classroom approach follows a team-based learning (TBL) model (*33*).

Course

Second-year Analytical Chemistry

Context

One hundred seventy-five (175) students in a fixed-seating lecture style theatre. Lectures were 1 hour 20 minutes and met twice per week. In each class, there was one instructor and one TA.

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Organization

Students work in teams during class. The teams were selected by the instructor which is consistent with the TBL model (*33*). Five to six students were assigned to a team at the start of the course based on gender and their performance in first-year Chemistry. Ideally each team had at least one student who achieved an "A" in first-year Chemistry and at least 2 females. These teams did not change throughout the term. A map of the lecture hall where teams were assigned to sit was also provided at the start of term through the online courseware to save time getting students organized during lecture.

Example Topic

The example topic described here involves absorption and emission spectrometry as well as figures of merit. Figures of merit are quantitative characteristics that are derived from measurements and used to evaluate an analytical technique. Some figures of merit include: accuracy, precision, sensitivity, selectivity, and detection limit.

Pre-Class Assignment

Students were told to read sections from the course textbook, Harris, *Quantitative Chemical Analysis*, 8th Edition related to Absorption and Emission spectrometry. Generally, the pre-reading assignments were 3-7 pages long with 2-4 questions provided to guide students through the reading.

Student Accountability

At the start of class students were given a multiple choice quiz that tested the pre-reading material. A sample question is provided in Figure 1. The students complete this quiz individually and then again as a team to ensure that all team members have a fundamental understanding of the reading material. This requires the first 25 minutes of class time.

1. Which of the following statements about absorbance is true?

a. Increasing the intensity of the light shined on an absorbing sample will increase the measured absorbance value.
b. Absorbed light can cause electrons to move from n to π^* molecular orbital.
c. A singlet state can not be created directly by absorption.
d. Absorbing a photon of light will always result in a photon being released at a later time.
e. An absorbed photon can cause a vibrational OR electronic transition, but not both.

Figure 1. Sample question from pre-reading quiz.

In-Class Challenging Problem

Students were provided with a scenario and asked to make decisions regarding that scenario. The in-class challenging problem used is provided in Figure 2.

Application Activity 1

Preamble

Heavy metal pollution poses risks for human health and the environment. Heavy metal mercury (Hg) has a variety of natural and anthropogenic sources such as use in fungacides, and combustion of fossil fuels. Once introduced in the marine environment, mercury can be converted to methylmercury, which enters the food chain and accumulates in higher marine organisms, particularly edible fish. Research has shown that methylmercury has the capacity to bioaccumulate to concentrations that are a million-fold that of the concentrations in seawater. Mercury is present at ultratrace levels in natural waters and the determination of Hg at these levels has been a challenge to analytical chemistry.

You work for the city's water board and your primary role is to analyze for total Hg in river water samples. The usual technique used to analyze mercury in water samples (cold-vapor Atomic Absorption water monitoring system) is broken. However, there are 3 analytical techniques available to you.

All three techniques require some sample preparation where the water sample is pH adjusted and all of the various mercury compounds present in the water sample are converted to dissolved Hg^{2+} ions.

Decision Task

Based on a set of criteria and the information given, choose a technique that would be most appropriate for this task.

A. Gravimetric analysis

The river water sample is pre-concentrated. Reagent A (thioacetamide, CH_3CSNH_2) is added. Mercury II ions in the sample react with reagent A and form a precipitate, HgS: The precipitate is filtered, collected and weighed. Based on the weight, the amount of total mercury initially present (moles) is determined.

B. Spectrophotometric determination

Sulfuric acid and KI are added to the river sample containing mercury. A color-forming reagent, (Rhodamine-B) is added to the river sample. A reaction occurs between Hg and the color-forming reagent in a 1:1 ratio to form a colored complex (Rhodamine-B-Hg(II) iodide complex). The colored solution is analyzed using the UV/VIS spectrometer at the analytical wavelength, 556 nm. A set of calibration standards are made and a calibration curve is created.

C. Fluorescence

The water sample containing Hg is pH adjusted to 7. A fluorescent-forming reagent (MS 1; Nolan and Lippard, 2003) is added to the sample solution. A reaction between Hg and the fluorescent-forming reagent in a 1:1 ratio occurs to form a compound that fluoresces. This intensity of the fluorescence is measured at 530 nm. A set of calibration standards are made and a calibration curve is created.

Figure 2. Sample In-Class Challenging Problem.

As shown in Figure 3, each team of students were instructed to come up with a set of criteria that could be used to evaluate the three techniques in the scenario. Essentially, the students were generating a list of figures of merit. Then, the students were tasked with choosing the most appropriate technique based on the criteria that they created. Each team submitted their answers at the end of class. During their discussions, the instructor and a teaching assistant walked around to answer questions and ask probing questions to further team discussions. Students often asked questions to explore the limits of the information provided. For example, a student asked what species in a river sample would interfere with analyzing total mercury to help them decide which technique was most appropriate. Students were encouraged to think about how they could find that information themselves. They were also surprised to see that an exact answer was not available because of varying factors such as environment.

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Application Activity: Team Discussions

Assign one group member to be the recorder and answer the following questions as a team. You may use point form.

1. Come up with a set of criteria to evaluate the three methods (For example, "cost" could be one criteria). Record on the table below.

2. In the following table, comment and/or rank each method according to your criteria (for example, gravimetric analysis would be the cheapest. You may leave some spaces blank).

Criteria	Gravimetric analysis	Spectrophotometry	Fluorescence
Cost	Cheapest	Medium	Most expensive

3. Prioritize your criteria and select the top 3 criteria for the scenario given.

4. Based on your top 3 criteria, choose a technique that would be most appropriate for this task. Provide reasons for your choice.

5. (Time permitting) What if the measurement of total Hg had to be made in the field? Re-rank your criteria and select a technique that is appropriate for this scenario.

Figure 3. Examplar Discussion Questions

Instructor-Led Discussion

Once all groups came to a decision, the instructor facilitated a discussion between the teams. During the discussion, students were encouraged to argue their points of view. The emphasis was the reasoning behind the answer. After the discussion, the instructor summarized the key points including the important figures of merit and the difference between absorption and fluorescence spectrometry. The instructor-led discussion sometimes continued into the subsequent class meeting.

How the Flipped Classroom Can Promote Sophisticated Epistemology

In the exemplar provided, there were some indications of sophisticated personal epistemology from students based on in-class observations by the instructor, student-generated documents, and student responses to the end of term survey. The first example is that students were not solely relying on the instructor for knowledge but on themselves and their peers. In the exemplar, students co-create figures of merit based on their prior knowledge, discussion with peers and the pre-class reading assignment. Students were tasked with completing the in-class discussion questions which included generating a criterion to assess analytical methods (Figure 3). Teams were expected to come up with "accuracy", "precision", "sensitivity", "selectivity" and "detection limit". The student submissions show that all groups generated a list that included some correct figures of merit but may have used different terminology to describe them. Approximately 30% of the groups missed three or more figures of merit while the other 70% missed zero, one or two. In the end of term survey, a student commented, "Being able to discuss your thinking helped me better understand the material. My classmates sometimes would explain things a little differently than the prof, so it gave me another way to approach a concept." Another student writes: "I first tried the problems by myself to figure out what I still didn't understand. Then as a group we re-evaluate the same problems and I really learned a lot from people in my group." These responses indicate that students are seeing themselves as a source of knowledge. This is very different from what would transpire in a traditional class. A traditional class would involve the instructor lecturing on absorption and emission spectrometry and describing various figures of merit. Students would be told how the figures of merit are used to assess analytical techniques for a particular problem. In the flipped classroom approach, students are not fed information in a lecture but instead given the responsibility to learn material on their own with some guidance. We can expect that flipped classroom approach encourages an increased level of self-confidence and this is supported by a study on flipped classrooms in General Chemistry that reported an increase in student self-confidence when problem-solving (*34*). The flipped classroom also facilitates viewing knowledge as complex, rather than consisting of simple facts. During the instructor-led discussion in the exemplar, teams argued between options B (Absorbance) and C (Fluorescence) (Figure 2). There were good reasons for both options so it was essential to acknowledge that the explanations behind the choice were important. Although one choice was better than the others, there was no wrong answer. By exposing students to more challenging questions and emphasizing the reasons behind a team's choice, students move from viewing knowledge as rules to memorize to seeing knowledge as more complex. The exemplar also led to incidents where knowledge was potentially seen as both limited and expanding. During the team discussions, students asked for information that was not provided in the current material. An example would be, "What are the interfering species for analyzing for total mercury?", with the expectation that the answer would be a pre-determined list. The instructor encouraged students to think about how they could find this

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information and that a full answer may not be known for all environments. The student realizes that knowledge in this area is not "finished" but continues to be explored. In the end of term survey, a student commented, "I even researched more about a few of the topics we covered to learn more…" By exploring a topic outside of class, the student has the opportunity to read about areas currently being expanded upon. These incidents indicate that a flipped classroom approach similar to the exemplar has the potential to facilitate sophisticated views of the source, simplicity and tentativeness of knowledge.

Conclusions

A flipped classroom approach has the potential to facilitate the development of sophisticated epistemology. In the exemplar provided, the flipped classroom approach specifically encouraged the views that knowledge is complicated, limited, expanding, and that learners themselves are capable of contributing to that knowledge. A sophisticated epistemology is important because it arises from a deep understanding of the nature of knowledge and knowledge construction. Perhaps without even realizing it, undergraduate education aims to shift student epistemology. Studies indicate that in general, university students view knowledge as simple (right or wrong answers), they look towards an external authority such as the instructor as the holder of knowledge and they view knowledge as unchanging and a dead end (*7–10*). However, as educators, we want students to leave our classrooms having the skills of a researcher: critical thinkers, work independently as well as collaborate with peers, have an understanding of how knowledge is constructed and see themselves as being able to contribute to the current body of knowledge (*4*, *5*). This is a noble goal, and one way it can be better achieved is through flipped classroom teaching.

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Chapter 8

Active Learning in the Flipped Classroom: Lessons Learned and Best Practices To Increase Student Engagement

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The flipped classroom utilizes active learning in the classroom to increase student engagement. This is made possible by the delivery of course content outside the classroom, commonly in the form of video instruction. This chapter describes strategies for enhancing pre-class activities that shift the focus away from traditional video lectures and center around active learning strategies, such as reading and annotating the textbook in a social learning platform and completing tutorial based on-line homework problems. Best practices in a flipped classroom approach focused on peer instruction are shared for lecture, recitation, and even out of class sessions in a large enrollment general chemistry course.

Introduction

After spending several years teaching general chemistry using the traditional lecture method familiar to most undergraduate students, I decided to flip my classroom in the Spring of 2011. Class time is flipped inside out as the lecture space transforms into an active learning environment consisting of problem solving, in-class assignments, and discussion. Active learning is stressed in a flipped classroom, which maximizes critical thinking and collaboration; it also reinforces course material more effectively than the traditional lecture (*1*).

Breaking the mold of the traditional lecture in the classroom may seem difficult, and the best practices are not necessarily the most instinctual ones. The perceived difficulty involved with implementing a flipped classroom has

caused many instructors -- especially those at institutions with large class sizes -- to be skeptical and hesitant to try flipping their classrooms. These instructors question whether breaking the traditional lecture mold can be done successfully and whether it can be executed in a large lecture space.

It has been five years since I decided to flip my classroom, and I can affirm that it can be executed successfully in a large scale university classroom. However, implementing a flipped classroom has not been a perfect science. I tried many techniques, some of which have failed and some of which grew into a successful flipped classroom model. I learned from my experiences and have made changes in response to what I learned. My trials and tribulations in implementing a flipped classroom have resulted in a better approach. This chapter shares some of my insights and best practices for promoting student learning and active engagement in the flipped classroom.

Background

I began teaching at The Ohio State University in the Fall of 2007. My responsibilities included teaching the General Chemistry sequence for science majors with a typical class size of ~300 students. For about four years I taught in a traditional format by writing out my notes on the chalkboard as students copied them into their notebooks. A former chemistry student of mine, named Eric Langenderfer, approached me with the idea of a flipped classroom and told me about a video production course he took. I did some background research on it and made the decision to flip my classroom. In the Spring of 2011 I took the first step to flip my class by recording my traditional lectures in class as they happened, then posted them in small segments to the FusChemistryVideos YouTube channel (*2*). This occurred in the last ten weeks of the General Chemistry sequence. The remaining general chemistry lectures were recorded during the summer outside of class and were also uploaded to YouTube and later iTunesU (*3*). Once a video library of over 300 lecture videos was established, the in-class lecture time shifted from traditional chalk talk lectures to clicker questions. Students were equipped with Turning Technologies clickers, which allowed me to view student responses in real time. As technology evolved, the clickers were replaced by smartphones, as students used Poll Everywhere (*4*) to text in responses to lecture questions. In the Spring of 2013 I transitioned to Learning Catalytics (*5*), which better facilitated peer instruction compared to the other student response systems; it is still being used in my current classroom. The key to a successful flipped classroom is to expose students to the chemistry content before they ever set foot into the classroom. This is achieved through pre-class activities.

Effective Pre-Class Activities

A library of lecture videos, 337 in all, were created with the intention of preparing students for class. If I had to do it all over again, I would not have created any of them. I quickly found that all pre-class activities are not equally effective. In a traditional lecture setting, the focus is on the transfer of information and the pace

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is set by the lecturer. Students are passive and there is no mechanism to determine if students are intellectually engaged with the material. Their attention decreases with time, and lectures are not suited to promote critical thinking skills and higher orders of thinking (*6*). These reasons have prompted many instructors to flip their classroom in the typical and predictive manner of recording their lectures and then assigning viewing for homework. However, the same drawbacks of traditional lectures are exacerbated in lecture videos: students are still passive, their attention decreases with time, the lectures do not promote critical thinking, and now the experience is individualized and isolated (*7*, *8*). A great deal of time, thought, and energy has been devoted to come up with ways to ensure students are watching the videos before class, but instead of focusing our time and effort on ways to force students to watch traditional lecture videos on-line, shouldn't we be coming up with ways to facilitate active learning before class? Ideally, we could assign textbook readings before class to encourage the student to be "active" and set their own pace of transfer. Unfortunately, the experience is still individual/isolated, there is no real accountability to read the text, and many of our students don't know how to properly read a textbook for optimal learning. The strategy I use to actively engage students in the course content before lecture involves students reading and annotating the textbook through a social learning platform called *Perusall* (*9*) and completing MasteringChemistry™ (*10*) tutorial problems. A sample pre-lecture assignment is shown in Figure 1.

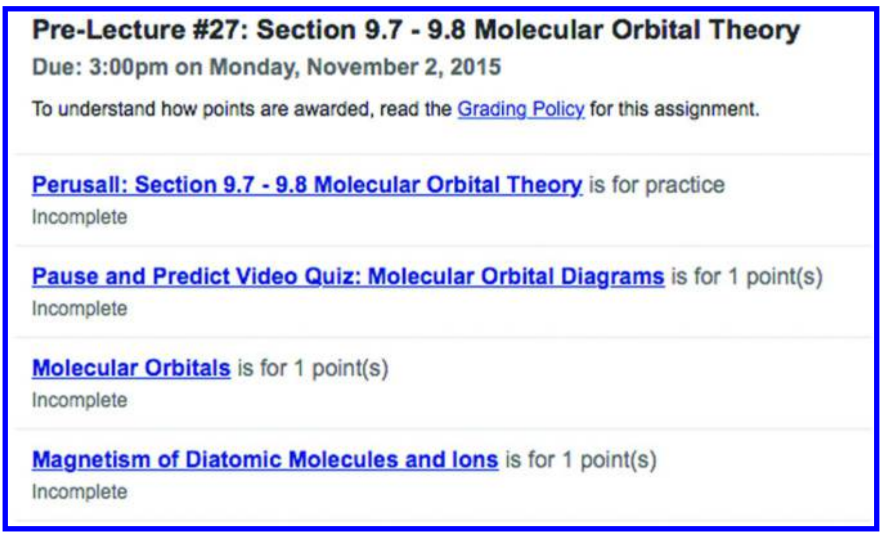

Figure 1. Sample pre-lecture assignment including link to Perusall reading and MasteringChemistry™ tutorial problems.

Perusall: Every Student Prepared for Every Class

Brian Lukoff, Gary King, Kelly Miller, and Eric Mazur had a vision of preparing every student for every class. They also wanted to carry out this vision without adding a heavy workload to the instructor. Their solution? Turn the

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out-of-class component into a social interaction, by creating *Perusall.* Essentially, a PDF of the textbook (or any PDF document) is uploaded into the *Perusall* platform. *Perusall* is designed to help students master readings faster, understand the material better, and get more out of class. To achieve this goal, students collaboratively annotate the textbook with other students from class. Students annotate the readings and asynchronously respond to each other's comments and questions about the reading in context. While students read, they receive rapid answers to their questions and help classmates resolve their questions (which also helps them learn). At the same time Perusall uses data analytics to advise the instructor how to make class time most productive by generating a confusion report, which will be described in detail below. Students start a new annotation thread in *Perusall* by highlighting text, asking a question, or posting a comment; they can also add a reply or comment to an existing thread. Each thread is like a chat with one or more members from the class, shown in Figure 2. The goals in annotating each reading assignment are to stimulate discussion by posting good questions or comments and to help others by answering their questions.

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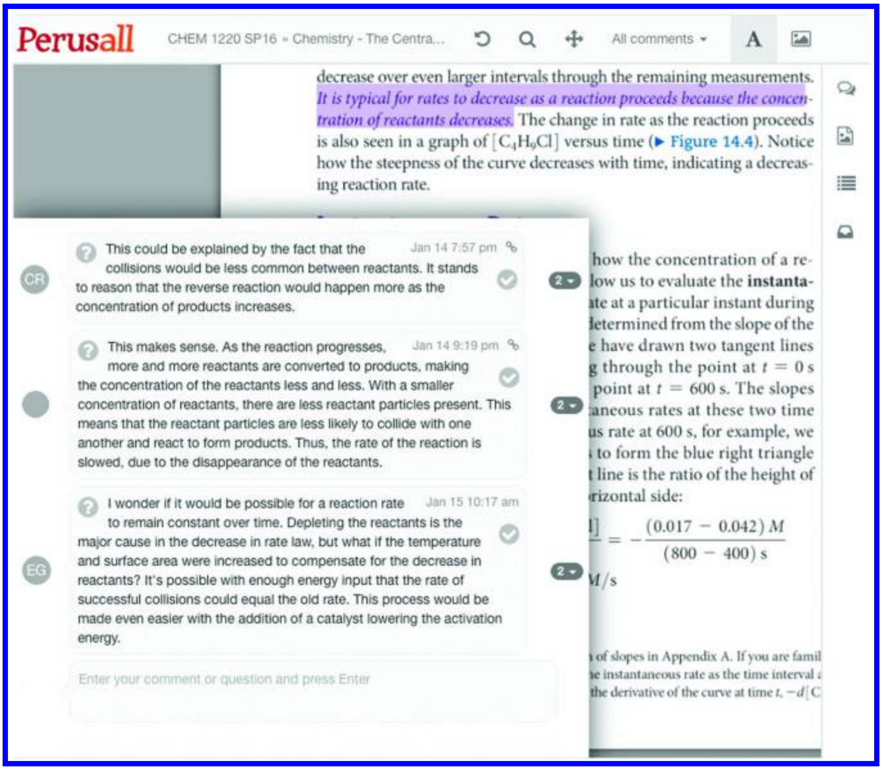

Figure 2. A Perusall annotation thread. Students commented on "It is typical for rates to decrease as a reaction proceeds because the concentration of reactants decreases" from the text. Their annotations are shown to the left. (Perusall images reproduced with permission from reference (9). Copyright 2016 Perusall.)

The *Perusall* grading rubric, which is posted on-line for instructors to provide to students, defines “annotating thoughtfully” by noting that “effective annotations deeply engage points in the readings, stimulate discussion, offer informative questions or comments, and help others by addressing their questions or confusions.” Students annotations are evaluated on the basis of quality, timeliness, quantity, and distribution. These annotations are graded automatically by an algorithm. *Perusall* assignments are due before each lecture, which enables me to start class by discussing information from the automatically generated “confusion report,” shown in Figure 3, and is a one-page summary of concepts my students had the most trouble with or questions about. The confusion report gives the instructor a summarized list of actual student comments, which are generated from the portions of the text that are annotated most frequently.

The beta test used with my students in the fall of 2015 and the spring of 2016 was free for students, but *Perusall* is currently working with multiple publishers to come up with a pricing plan that would add to the cost of the digital textbook. Students must be connected to the internet in order to make their comments/annotations.

Once students have completed their reading and annotations in *Perusall*, they are then prompted to complete MasteringChemistry™ tutorial problems.

MasteringChemistry™ Tutorials

The MasteringChemistry™ tutorials are ideal for students to work through after they have read and annotated the textbook in *Perusall*. Rather than passively watching a lecture video, students are completing problems on material that will be presented in lecture. In these assignments students are in “learning mode” as they have unlimited attempts to complete each problem and there are no penalties for opening hints. These assignments are designed to expose students to the topics covered in class and to have them think about the content before class starts. Students receive full credit for these problems when they arrive at the correct answer.

MasteringChemistry™ tutorials provide students with hints and feedback. Feedback should: focus students on the key knowledge you want them to learn, be provided at a time and frequency when students will most likely use it, and be linked to additional practice opportunities for students (*11*). The feedback provided by MasteringChemistry™ tutorials meets all of these objectives. An example of a pre-class tutorial problem on Molecular Orbitals is shown in Figure 4.

The homework assignment is called a tutorial because the student can opt to use one or more provided hints, which in themselves might require the student to enter answers, before proceeding to submit their answer to the overall problem. Figure 5 shows the available hints for the problem given in Figure 4.

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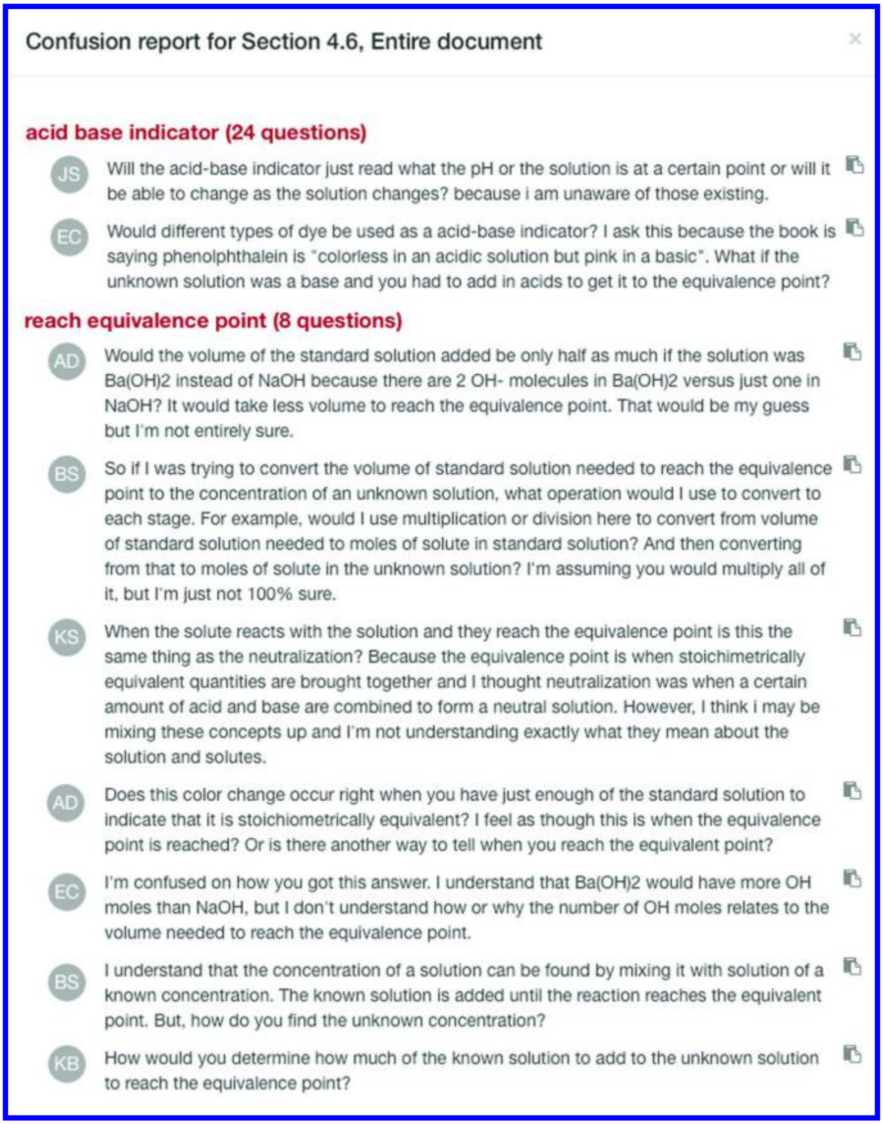

Confusion report for Section 4.6, Entire document

acid base indicator (24 questions)

JS Will the acid-base indicator just read what the pH or the solution is at a certain point or will it be able to change as the solution changes? because i am unaware of those existing.

EC Would different types of dye be used as a acid-base indicator? I ask this because the book is saying phenolphthalein is "colorless in an acidic solution but pink in a basic". What if the unknown solution was a base and you had to add in acids to get it to the equivalence point?

reach equivalence point (8 questions)

AD Would the volume of the standard solution added be only half as much if the solution was Ba(OH)2 instead of NaOH because there are 2 OH- molecules in Ba(OH)2 versus just one in NaOH? It would take less volume to reach the equivalence point. That would be my guess but I'm not entirely sure.

BS So if I was trying to convert the volume of standard solution needed to reach the equivalence point to the concentration of an unknown solution, what operation would I use to convert to each stage. For example, would I use multiplication or division here to convert from volume of standard solution needed to moles of solute in standard solution? And then converting from that to moles of solute in the unknown solution? I'm assuming you would multiply all of it, but I'm just not 100% sure.

KS When the solute reacts with the solution and they reach the equivalence point is this the same thing as the neutralization? Because the equivalence point is when stoichimetrically equivalent quantities are brought together and I thought neutralization was when a certain amount of acid and base are combined to form a neutral solution. However, I think i may be mixing these concepts up and I'm not understanding exactly what they mean about the solution and solutes.

AD Does this color change occur right when you have just enough of the standard solution to indicate that it is stoichiometrically equivalent? I feel as though this is when the equivalence point is reached? Or is there another way to tell when you reach the equivalent point?

EC I'm confused on how you got this answer. I understand that Ba(OH)2 would have more OH moles than NaOH, but I don't understand how or why the number of OH moles relates to the volume needed to reach the equivalence point.

BS I understand that the concentration of a solution can be found by mixing it with solution of a known concentration. The known solution is added until the reaction reaches the equivalent point. But, how do you find the unknown concentration?

KB How would you determine how much of the known solution to add to the unknown solution to reach the equivalence point?

Figure 3. A Perusall Confusion Report. For the reading of Section 4.6, 528 students made 1,885 annotations. The algorithm in Perusall summarized these annotations down to 32, which are accessible to the instructor with a simple click. Reading these just minutes before class gives the instructor valuable information of where the students are before lecture. (Perusall images reproduced with permission from reference (9). Copyright 2016 Perusall.)

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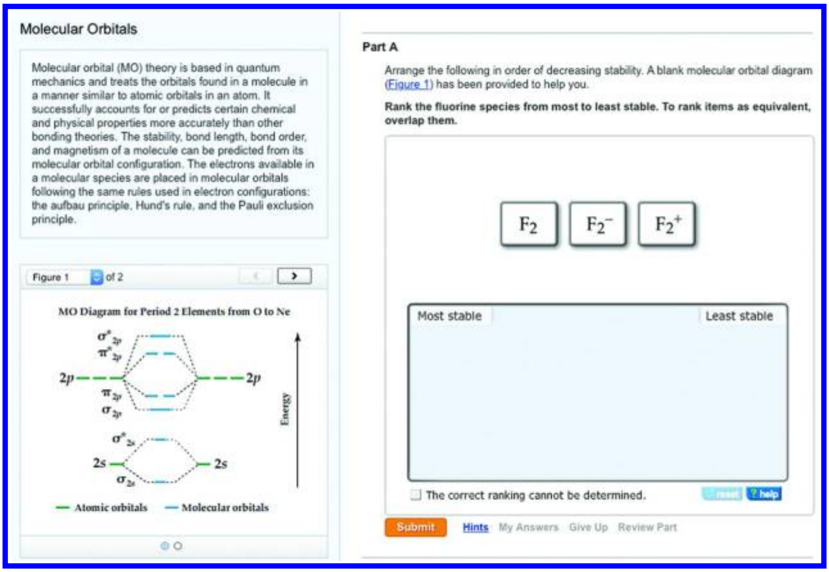

Figure 4. A MasteringChemistry™ pre-class tutorial problem. (MasteringChemistry™ images reproduced with permission from reference (10). Copyright 2016 MasteringChemistry™.)

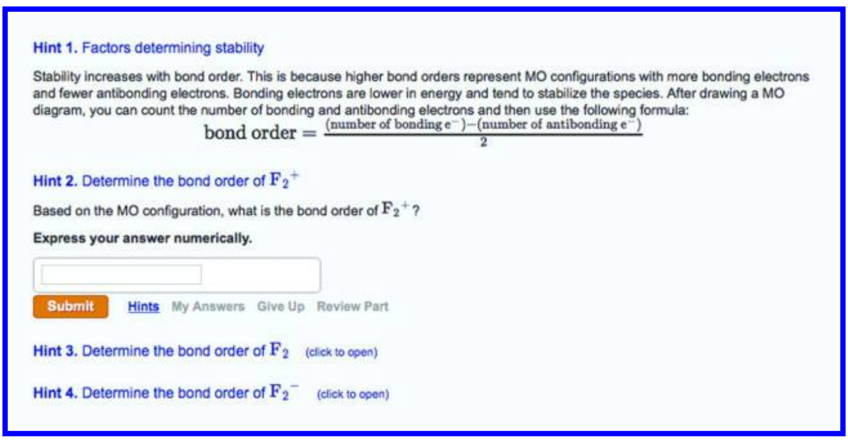

Figure 5. Hints provided to the Molecular Orbital tutorial in Figure 2. (MasteringChemistry™ images reproduced with permission from reference (10). Copyright 2016 MasteringChemistry™.)

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In addition to the standard tutorial problems, MasteringChemistry™ also contains an extensive list of interactive assets, which include Animations, Interactive Activities, Simulations (*12*), and Pause and Predict videos, which are my personal favorite. The Pause and Predict videos, an example of which is shown in Figure 6, consist of popular lecture demonstrations that many instructors use in class. Students first launch the video and background information is given about the demonstration. The video is strategically paused and the students are prompted to use their chemistry knowledge to make a prediction of the outcome of the demonstration. After the student makes their prediction, the video proceeds and they can see if what they predicted was correct or incorrect. Upon completion of the Pause and Predict video, students are given a few questions to answer, with hints and wrong answer feedback, based on the content of the video.

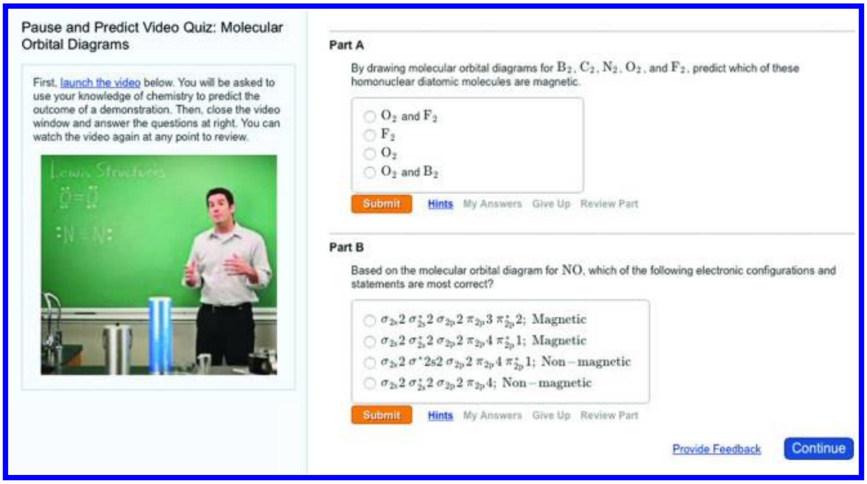

Figure 6. Pause and Predict video for Molecular Orbital Diagrams with associated quiz questions. (MasteringChemistry™ images reproduced with permission from reference (10). Copyright 2016 MasteringChemistry™.)

In addition to these tutorial questions, each pre-lecture assignment includes the learning goals for the upcoming lecture, an introduction to the content, a link that sends students to the *Perusall* reading assignment, and links to the traditional lecture videos on YouTube, which is shown in Figure 7.

Now that the students have been introduced to the content via *Perusall* and MasteringChemistry™ before lecture, Learning Catalytics is used in lecture to facilitate peer instruction.

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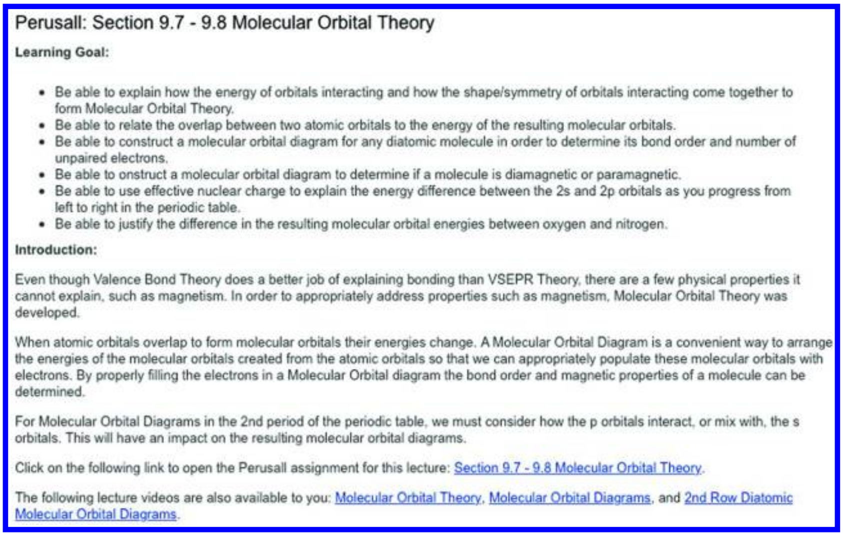

Perusall: Section 9.7 - 9.8 Molecular Orbital Theory

Learning Goal:

- Be able to explain how the energy of orbitals interacting and how the shape/symmetry of orbitals interacting come together to form Molecular Orbital Theory.
- Be able to relate the overlap between two atomic orbitals to the energy of the resulting molecular orbitals.
- Be able to construct a molecular orbital diagram for any diatomic molecule in order to determine its bond order and number of unpaired electrons.
- Be able to onstruct a molecular orbital diagram to determine if a molecule is diamagnetic or paramagnetic.
- Be able to use effective nuclear charge to explain the energy difference between the 2s and 2p orbitals as you progress from left to right in the periodic table.
- Be able to justify the difference in the resulting molecular orbital energies between oxygen and nitrogen.

Introduction:

Even though Valence Bond Theory does a better job of explaining bonding than VSEPR Theory, there are a few physical properties it cannot explain, such as magnetism. In order to appropriately address properties such as magnetism, Molecular Orbital Theory was developed.

When atomic orbitals overlap to form molecular orbitals their energies change. A Molecular Orbital Diagram is a convenient way to arrange the energies of the molecular orbitals created from the atomic orbitals so that we can appropriately populate these molecular orbitals with electrons. By properly filling the electrons in a Molecular Orbital diagram the bond order and magnetic properties of a molecule can be determined.

For Molecular Orbital Diagrams in the 2nd period of the periodic table, we must consider how the p orbitals interact, or mix with, the s orbitals. This will have an impact on the resulting molecular orbital diagrams.

Click on the following link to open the Perusall assignment for this lecture: Section 9.7 - 9.8 Molecular Orbital Theory.

The following lecture videos are also available to you: Molecular Orbital Theory, Molecular Orbital Diagrams, and 2nd Row Diatomic Molecular Orbital Diagrams.

Figure 7. Introduction to the pre-lecture assignment covering Section 9.7 – 9.8 Molecular Orbital Theory. This includes learning goals, and introduction, a link to the Perusall assignment, and links to the traditional lecture videos on YouTube. Each pre-lecture assignment has an introduction similar to this one.

Peer Instruction with Learning Catalytics

The biggest challenge and time commitment in the flipped classroom -- or in any classroom that employs active learning strategies -- is to come up with effective polling questions for students to complete in class. In my first iteration, I simply used old exam questions, which were all multiple choice. Selecting the correct polling question depends on the polling platform the students are using. I initially used Turning Technologies clickers and later transitioned to an on-line platform Poll Everywhere. When these questions were delivered to students they either worked together in groups or worked on the problems individually and then discussed their responses with their neighbors. Class seemed interactive, but I was not seeing the type of discussions I would have liked. Clickers did very little to optimize student discussion, as students would simply turn to their neighbor with little discussion. Managing time was also difficult. I began to look for a better in-class solution and determined the research of Eric Mazur (*13*, *14*) was well suited for my needs. Mazur assembled a team and developed a new platform, called Learning Catalytics, that was built and designed around pedagogy, as opposed to technology. His team used intelligent algorithms and data analytics to improve questioning, manage discussions, and facilitate the flow and time management of the lecture. After discussing the capabilities of Learning Catalytics with Brian Lukoff, the co-founder of Learning Catalytics, in the Spring of 2013 I shifted the focus of my lectures and recitations to Peer Instruction. This involved switching from Poll Everywhere to Learning Catalytics after spring break of that semester.

Learning Catalytics is a "bring your own device" student engagement, assessment, and classroom intelligence system. It has allowed me to promote peer-to-peer learning with real-time analytics, and using Learning Catalytics has vastly improved my classroom. Learning Catalytics has over 18 different question types, which allowed me to expand beyond simply asking multiple-choice questions. It is possible to ask good multiple-choice questions, but this task is difficult and time consuming. It's not hard to come up with good questions, but coming up with meaningful distractors is challenging. The beauty of Learning Catalytics is not simply the question types available, it's the ability to facilitate peer instruction.

As students arrive to class they log in to Learning Catalytics and select the seat they are sitting in. The question is delivered to the students through the Learning Catalytics platform on their devices. As the question is delivered, the students are given instructions to not interact with their classmates and submit their answer individually. The instructor can see the responses in real time, as a seat map like the one in Figure 8 is generated.

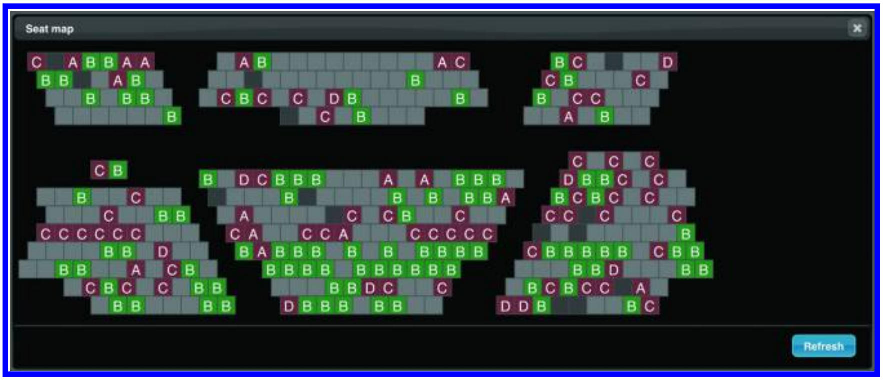

Figure 8. Learning Catalytics seat map displaying the student responses in the individual round of a lecture question. (Learning Catalytics images reproduced with permission from reference (5). Copyright 2016 Learning Catalytics.)

Once students have made an individual investment in their answer they are more likely to engage in a fruitful discussion with their classmates. If you take a closer look at the seat map, you also see that if I would instruct students to simply turn and talk to their neighbor, they might not get the best out of the discussion. But wouldn't it be great to be able to place students into groups where at least one student has a different answer than their classmates? Then have these students argue about the problem and discuss the correct answer? That is exactly what Learning Catalytics facilitates: after the instructor hits the "Assign Groups" button, students are delivered a message, which indicates the classmates they should have a discussion with. After discussion, Learning Catalytics will then repoll students to see the impact of the discussion on student understanding. For advanced users, Learning Catalytics also has a smart timer, which will start and stop the polling based on how many students have responded. When I first started

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using Learning Catalytics, I was amazed at how much louder the volume of the room was compared to other polling platforms. Instead of simply looking to a classmate for the answer to the question, students already have work completed and they are having discussions. As I began to use Learning Catalytics more and more I began to modify how I facilitated discussions. For example:

What will be the outcome of the following two steps?

I. Take 50.0 mL of 1.0 M barium hydroxide and mix it with 50.0 mL 1.0 M hydrochloric acid and place them in beaker A.
II. Add 120.0 mL of 1.0 M zinc nitrate to Beaker A

a. No precipitate will form and the solution will be acidic
b. No precipitate will form and the solution will be basic
c. A white precipitate will form and the solution will be neutral
d. A white precipitate will form and the solution will be acidic
e. A white precipitate will form and the solution will be basic

The question is delivered to the students in Learning Catalytics and they are instructed to work through and think about the answer and submit their response. As the students are finishing up their individual work, I write the following questions on the board:

1. How would you use the solubility guidelines to write out the net ionic equation and determine the precipitate that formed, the limiting reactant, and the excess ions in solution?
2. What makes a solution acidic/basic?

Just before I group the students I make the following announcement: “In addition to arriving at the correct answer, I want you and your group to think about the questions I have written on the board. After the group round is finished I will select one student at random to give me a report of how your group arrived at the answer you selected and how the answers to the questions on the board helped you arrive at that answer.” To a student in a classroom of 350 students, this can be very intimidating, but since I added this wrinkle, the group discussion has been much more focused. This also promotes communication and collaboration among our students. In many instances, students have the right idea, but they do not articulate their answer in the way a chemist would. Emphasis is then placed on the proper vocabulary to use when communicating with other chemists. This method of in-class discussion has worked well in getting students engaged productively. However, I noticed that students were still not taking notes like I would like them to.

Taking Notes in a Flipped Classroom

One trap that students fall into in a flipped classroom is that they do not take organized notes during class. Students write out their work for the individual

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round, but not many of them write out my explanation after the group discussion. Instructors in a flipped classroom cannot overlook the fact that they need to outline and encourage effective note taking. To facilitate this, I created the following template, Figure 9, and posted it on our Learning Management System for students to print out and bring to class.

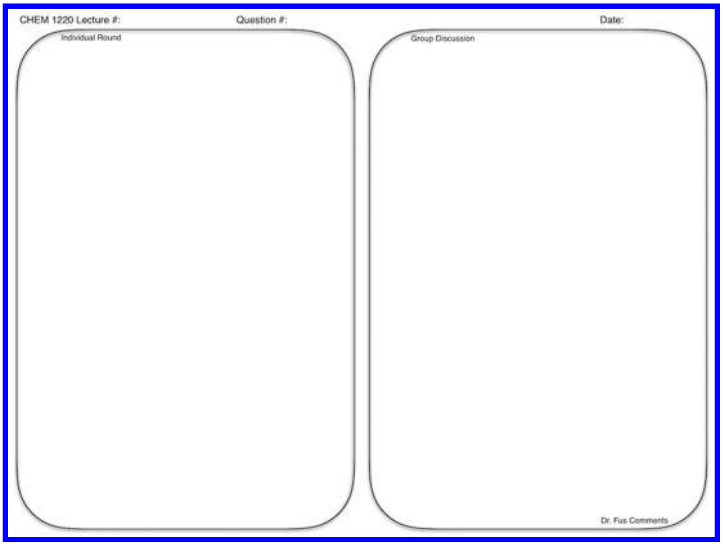

Figure 9. Note taking template for students in a flipped classroom. Source: Author's own image.

In this template, there is room for students to write out their work to the individual round and group discussions. I encourage them to write down the group discussion questions that I list on the board. I also make the effort to write out the key points of my explanations on the board and constantly encourage students to record them in their notes. There is also a place at the bottom of the page to list end of chapter problems from our textbook for additional practice. I direct students who incorrectly answer a question in the individual round to complete these questions and each recitation activity is based on the content of these questions.

Team-Based Learning in Recitation

The final three sections of this chapter have been a great addition to my flipped classroom, but these strategies would be helpful in many other classrooms. The same technology that supported my flipped classroom also supports techniques

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used in recitation as well. Beyond class polling, Learning Catalytics has a Team-Based Assessment mode that is extremely useful in recitation. In this mode, students respond individually to all questions in the module, and then gather in groups to respond as a team to the same set of questions. At the beginning of recitation, the Teaching Assistant places students into groups and they enter their group name in Learning Catalytics and complete the individual round of questions. In the group round, students can see the answers of the entire group and they must agree on what answer they submit as a group. If the group answers the question correctly on their first response in the group round, they receive full credit. If the group answers correctly on their second try, they receive half credit. And if they answer correctly on the third try the group receives quarter credit (these settings are customizable). To generate the best discussions in the group round, I aim to write questions with a 50% average in the individual round. Instructors can also determine what percentage of the assignment they want to assign to the individual and group rounds: I assign 20% of the grade to the individual round and 80% of the grade to the group round. Using Learning Catalytics also saves time for the Teaching Assistants because all grading is done automatically by the Learning Catalytics platform.

Exam Prep Assignments

Self-testing involves answering practice questions about previously studied material to enhance long-term learning. Current research has demonstrated that students who studied material and then took a practice test performed better on a later test than students who only studied the material (*15*). Every week, students are assigned timed exam prep assignments delivered on Mastering Chemistry. These assignments are designed to be low-stakes and give students a proper self-assessment of where they stand on a weekly basis. They are due every Sunday night at midnight and once students submit their answers they cannot access the assignment until after the due date. In the first iteration with my class, I became frustrated that students did not go back and work out the solutions to the problems they missed and as a consequence, the students missed similar questions again on the exam. To encourage students to look over the problems they missed I designed exam prep follow-up assignments, which are due every Friday evening. These assignments allow students to earn the points that they missed on the exam prep and these assignments are password protected, where the password changes each week. In order to gain the password students must come to my office hours, go to the TA help center, or attend a team led peer learning session. By coming to these sessions with worked-out solutions and having conversations about why their answer was incorrect, students not only know the right answer to the questions, but know why their answers are correct or incorrect. It also makes office hours more focused. The following template, shown in Figure 10, is used to encourage students to look over their work.

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Exam Prep Follow-Up

Go to Mastering Chemistry and review the Exam-Prep Assignment that was due Sunday at 11:59 pm. Complete the table indicating which questions you answered correctly/incorrectly

Exam Prep Assignment		
Question #1	☐ Correct	☐ Incorrect
Question #2	☐ Correct	☐ Incorrect
Question #3	☐ Correct	☐ Incorrect
Question #4	☐ Correct	☐ Incorrect
Question #5	☐ Correct	☐ Incorrect

For the questions you answered incorrectly, re-work them in the space below (and another page if necessary), showing all work to arrive at the correct solution. Once you have this complete, take this sheet to Dr. Fus' office hours (8-10 pm Wed in 1046 McPherson), the Peer Led Study Sessions (8-9:30 pm Thurs in 1046 McPherson) or go to 170 Celeste during on of the recitation TA office hours (posted on Carmen). After discussing what you did wrong on these problems, they will give you the password for the Exam Prep Follow-Up Assignment.

Figure 10. Exam prep follow-up assignment template for students to self-assess and work out the problems they missed. Source: Author's own image.

Student Assessment Plan

The Student Assessment Plan, which is the latest modification to my classroom, was implemented in the Fall of 2015 and is designed to identify at risk students in the first week of class and provide them with resources to succeed. This can be performed in any course, whether it is flipped or traditional, and it can also span a variety of disciplines.

Each fall, over 7,000 recent high school graduates enroll in courses at The Ohio State University. With each incoming class comes a group of students with increasingly higher composite ACT/SAT scores. As students transition from a high school to university setting, the role of the teacher in their educational experience changes. In some cases, particularly at Ohio State, students step into a college classroom comprised of more students than their entire graduating high school class. Many students go from high school to college with little preparation for this shift. This is particularly evident in General Chemistry, where about one-fourth of the students enrolled in CHEM 1210 (first-semester General Chemistry) during AU13-SP14 earned a grade of below C- or W (The Ohio State University Enrollment Services – Analysis and Reporting).

To identify how the students compared to their peers, students were given three forms of assessment during the first week of classes: an entrance exam, an American Chemical Society Concepts exam, and a survey on their chemistry background. Students were initially ranked from highest to lowest cumulative score on the ACS exam and the entrance exam, which was the first exam given from a previous semester covering up through stoichiometry. Based on these

scores initial cuts were made placing the students in five different groups. I also gave the students several poll questions, which also helped me target at risk students. The questions are shown below, with the at risk responses shown in bold.

Q1: Which statement below best describes your high school chemistry courses?

a) I did not take chemistry in high school
b) I only took one year of general chemistry
c) I took more than one year of general chemistry, but did not take AP Chemistry
d) I took both general chemistry and AP chemistry
e) I took both general chemistry and IB chemistry

Q2: How would you describe your high school instruction?

a) I had the best chemistry teacher and they should be nominated for national awards. I learned a great deal from them.
b) I had a great chemistry teacher. They are probably on of the best in the state. I learned a great deal from them.
c) My chemistry teacher was about average. I remember some of the concepts they taught.
d) My chemistry teacher was pretty bad. I don't remember too many concepts covered in high school.
e) My chemistry teacher was awful. I don't remember anything from high school.

Q3: Which math course did you place into?

a) MATH 1148 (college algebra)
b) MATH 1150 (pre-calc)
c) MATH 1151 (Calculus I)
d) MATH 1152 (Calculus II)
e) MATH 1161 (Accelerated Calculus I)
f) MATH 1181 (Honors Calculus I)
g) MATH 2153 (Calculus III)

Q4: Which statement best describes your class rank in high school?

a) I was valedictorian
b) I was in the top 10% of my graduating class
c) I was in the top 25% of my graduating class
d) I was in the top 50% of my graduating class
e) I graduated high school

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Students were placed in one of five groups based on their assessment scores and how many at-risk responses they had. They were directed to resources aimed to improve study skills and content knowledge and given a specific "assessment plan," which is summarized in Figure 11.

Group 1: Study Skills Workshop

Group 2: Office Hours, and Study Skills Workshop

Group 3: Peer Led Study Sessions, Office Hours, and Study Skills Workshop

Group 4: Friday Happy Hour Study Sessions, Peer Led Study Sessions, Office Hours, and Study Skills Workshop

Group 5: Dennis Learning Center (DLC) Academic Coach, Friday Happy Hour Study Sessions, Peer Led Study Sessions, Office Hours, and Study Skills Workshop

Figure 11. Suggested resources given to students based on performance of assessments. Source: Author's own image.

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These recommendations utilize campus resources in addition to the ones available within the chemistry department. The Dennis Learning Center offers Academic Coaches (*16*) to any Ohio State student and their office facilitated the study skills workshop (*17*) in the first week of class. In addition to these recommendations, students were reminded to attend the weekly sessions based on their exam prep assessment score.

Conclusion

This chapter is just a small glimpse into my classroom, recitations, office hours, and out of class activities. My intention in writing this is that each instructor can be inspired to take something I've written and use it to enhance their course. We all have different styles of teaching and there is no one size fits all approach to flipping the classroom. Even so, one thing is certain: the way our students access information is constantly changing and evolving in a world where new technological advances are made daily. We also need to strive to make changes and improvements in the way we educate our students. John Wooden said it best: "When you improve a little each day, eventually big things occur… Not tomorrow, not the next day, but eventually a big gain is made. Don't look for the big quick improvement. Seek the small improvements one day at a time. That's the only way it happens – and when it happens it lasts."

It's amazing to see how much progress has been made since I started flipping my classroom. My initial focus -- which was creating lecture videos -- has been shifted to activities that actively engage students. Platforms like *Perusall* and Learning Catalytics didn't even exist five years ago, but they now serve as the backbone for preparing and actively engaging the students in my classroom. I can't predict what the future will hold, but I am very eager to see what new products are coming that focus on pedagogy as opposed to technology and that will inspire our students to work harder and see better results. My journey as a flipped educator is only beginning and I hope that you are inspired to join me and the fellow chapter authors of this book to improve a little each day to make a lasting impression on our students.

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Chapter 9

Flipping for the Masses: Outcomes and Advice for Large Enrollment Chemistry Courses

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Flipped classroom methods, as with any active learning strategy, pose specific challenges when incorporated into courses with very large enrollments. This chapter presents a brief overview of studies indicating the efficacy of large flipped classes in general and organic chemistry. The structures of two large flipped classes are described and suggestions for overcoming the unique challenges of large enrollment courses are provided.

Early reports of flipped chemistry classrooms mainly focused on moderately sized chemistry classes at the high school level or chemistry classes in institutions of higher education with lower enrollment numbers. Often college instructors who teach lecture courses with enrollments of 200 students and above have a difficult time imagining how the new teaching method might be incorporated into a college level classroom environment. We have taught flipped chemistry classes ranging in size from approximately 200 to 400 students, and efficacy reports from classes of this scale are beginning to appear in the chemistry education literature (*1–5*). In this chapter we share the lessons we have learned flipping our large lecture courses.

Is Flipping a Large Classroom Effective?

Studies comparing the efficacy of flipped classrooms and traditional lecture formats in colleges and universities are beginning to emerge. Several early studies

have shown a relatively large effect of flipped class instruction (*6–9*). While these reports represent important steps in the analysis of flipped class efficacy, studies often lack accurate controls, are completed in inauthentic situations, and use short-term assessment techniques. Further studies are needed to determine how a flipped class method is applied best to a variety of students over an entire term (quarter or semester). Additionally, studies on courses consisting of non-chemistry majors and lower division students are needed to compare outcomes for classes in which students might not be intrinsically motivated to learn the material.

While initial studies on the impact of flipped classes focused on smaller classes, several studies on larger classes have been published recently. Rein and Brookes reported no change in exam scores or course completion rate but did find a positive change in course evaluations for a partially flipped organic chemistry course with an enrollment of approximately 200 students (*2*). Eichler and Peeples found no change in exam performance for a partially flipped general chemistry course with an enrollment of 452 students (*5*). This study did identify a small positive effect on course GPA and decrease in the failure and withdrawal rates for the flipped class group. An additional positive effect was identified for final course evaluations. In a fully flipped general chemistry course with enrollment of 415 students, Yestrebsky reported an improvement in final course grades for the flipped class as compared to a traditional class with exams of comparable difficulty (*3*). Flynn identified a small but statistically significant increase on final exam scores for a fully flipped organic chemistry course with 420 students enrolled (*4*). A reduction in withdrawal and failure rates was found for this group as well.

Although studies on our own flipped classes have not demonstrated statistically significant effects for students in these classes as a whole, our results revealed subsets of students who did benefit from the change in class format. The study design for the flipped organic chemistry classes required following non-chemistry major students onto the next course in the sequence to determine whether the flipped class format provided any lingering academic performance effect (*10*). The control group enrolled in a traditional organic chemistry lecture for both the first and second classes in the course sequence in two consecutive summer sessions while the treatment group enrolled in a flipped class for the first class in the sequence and a traditional lecture for the second class in the sequence in two consecutive summer sessions. Comparisons were made using final exam performance for the second class in the sequence and identical final exams were used for all comparisons.

Because the courses studied were offered in summer sessions, two distinct student populations were present. Some students were enrolled to get ahead with their studies while others were enrolled to repeat the class after not earning a passing grade during the regular academic year. Students who repeated the first term organic course consistently performed lower in the second term course than did students who completed the first term organic course on their first attempt (−1.243 standard deviations with $p < 0.001$).

While no statistically significant effect was observed for students taking the summer class to accelerate their academic progress, students who were retaking the class did benefit from the flipped class format (Table 1). Repeating students

who took the flipped class for the first course in the sequence outperformed their counterparts who took the traditional lecture format by an average of 0.605 standard deviations (equivalent to a 7.5-point increase in exam score on a 100-point scale), effectively narrowing the gap between the new and repeating students in the second organic chemistry course.

Table 1. Predicted Difference in Standardized Final Exam Score Between Flipped and Traditional Organic Chemistry Class By Year and Student Group.

Year	*Student Group*	*Standardized Coefficients[a] (standard error)*
2012	Non-repeater	−0.181⁺ (0.180)
	Repeater	0.595* (0.269)
2013	Non-repeater	−0.353⁺ (0.195)
	Repeater	0.615* (0.288)

[a] + < .10, * p < .05, ** p < .01, *** p < .001. The standardized coefficient (or effect size) estimates the magnitude of increase in the average final exam score measured in standard deviations when comparing the traditional to the flipped class.

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Student final exam performances for freshmen-level general chemistry courses (largely composed of non-chemistry majors) were not as dramatically improved as those outcomes demonstrated in the organic chemistry courses. Final exam outcomes consisted of a change of approximately +/- one-half a letter grade depending on the specific course, complications with technology tools encountered, and pre-class accountability checks implemented (*11*, *12*). Within the freshman chemistry courses, however, second year students and females experienced a significant positive impact (Table 2). For example, in a specific course the second year students had an overall effect size of 0.545, (p = 0.047) and first year females had an effect size of 0.249 (p = 0.055) (*12*). These effects correlate to an 8.87% and 4.05% increase in final exam scores, respectively. First year males, however, had an effect size of -0.276 (corresponding to a 4.49% final exam score decrease, p = 0.008). Evidence from surveys suggests this is due to differences in motivation levels. When combined, the groups show a generally small effect size. A low overall effect size on exams, however, does not indicate cause to avoid a flipped classroom format at the introductory level. Instead, further studies are needed to assess the long-term impact of flipped class instruction on students' knowledge retention and study skills that might not be apparent immediately. Additionally, adjustments to class structure must be made to encourage better study habits to help less motivated students.

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Table 2. Predicted Difference in Standardized Final Exam Score Between Flipped and Traditional General Chemistry Class By Year and Student Group.

Year	*Student Group*	*Standardized Coefficients[a] (standard error)*
2013[b]	All	0.192 (0.008)
2014	All	−0.107[+] (0.063)
	All Female	0.249[+] (0.129)
	All Male	−0.276** (0.104)
	All 2nd year	0.545* (0.274)

[a] + < .10, * $p < .05$, ** $p < .01$, *** $p < .001$. The standardized coefficient (or effect size) estimates the magnitude of increase in the average final exam score measured in standard deviations when comparing the traditional to the flipped class. [b] Only the overall effect is shown for 2013 because no differentiated treatment effect was detected with respect to student demographics.

How Do You Flip a Large Chemistry Class?

Generally, a class is flipped by moving significant components of content delivery outside of class time and bringing activities normally relegated to homework into the classroom. This common format works for classes of any size. Specific strategies and tools, however, should be included in large enrollment courses to assist in managing any accountability measures for pre-class work and provide interactivity during in-class activities.

Pre-Class Assignments and Accountability

In flipped classrooms, the non-compliance of select students has a ripple effect to the rest of the population. Though flipped classrooms do not increase the workload for students, the atypical distribution of study time can cause students to arrive to class unprepared. Peer instruction can't occur if significant numbers of the students are not completing their pre-class assignments. Habitual resistance to the methodology, procrastination, distraction and unintended missed assignments were commonly identified reasons for non-compliance and affected students of all motivation levels (*12*).

The same pre-class information delivery methods that work for small classes also work for very large classes. Students can be instructed to read textbook sections, watch lecture videos, or both before class. The exact mix of reading and video watching that is right for a given student will depend on the class and individual preferences. Short videos of approximately 5-10 minutes in length are ideal, although slightly longer videos might be necessary at times (*13*). These short video lengths keep students engaged and are easily watched on mobile devices. However, it can be difficult to focus on even short videos with the distractions of everyday life; embedding questions into the videos using programs such as Zaption

or Camtasia will encourage engagement in the video component of teaching (*14*, *15*).

When teaching very large classes in a flipped format, technology is the instructor's best ally. Students frequently require an incentive to complete pre-class videos or reading requirements, but a very large class size precludes the daily or even weekly use of any accountability method that requires manual grading. Quiz functionalities available in most learning management systems or electronic homework systems provide a method of accountability that can be administered before class time and graded automatically. Additionally, a class response system can be used to administer questions at the beginning of class. Questions used for accountability checks should not be particularly difficult. The purpose of these questions is to ensure students complete pre-class work. Questions to gauge comprehension can be included in accountability checks if one wishes to incorporate Just-in-Time Teaching methods into the course structure (*16*, *17*). Most importantly, it should be made clear to students that accountability checks are a low-stakes assessment to avoid undue student stress about submitting perfectly correct answers. Using difficult concept questions for these pre-class accountability checks is cautioned against in the large general chemistry classes where no amount of reassurance can adequately counteract the stress many new college students feel towards getting an answer wrong.

Adaptive programs such as ALEKS can be used if greater emphasis on problem solving is desired (*18*). It is important to note that students, especially young inexperienced students, may react negatively to difficult or lengthy homework assigned before class. However, much like the problems included for reading and video assignments, this can increase the quality of in-class work.

Some instructors designing their first flipped course use mandatory accountability checks as an "entrance ticket" for class due to concern about the likely presence of students who do not complete their assigned pre-class work. Neither of us has excluded a student from participating in class if they did not complete their pre-class assignments. We do, however, emphasize to students that we will not slow down class progress to accommodate failure to prepare to participate in class.

In-Class Time

A commonly asked question regarding very large flipped classrooms is "What do I do with in-class time when I have several hundred students?" The answer is anything that might help students learn. A typical class meeting includes a mixture of brief concept reviews, individual or group problem solving, and full class discussion of concepts or solutions. The key to managing in-class time with several hundred students is to leverage technology and instructional aides such as teaching assistants or peer tutors to instructor advantage.

Students in a flipped class will request a review of the pre-class material at the beginning of class. While a brief review can be helpful, one must be careful to avoid the rehashing of entire video or reading assignments; this type of presumed review of class material will disincentivize completion of future pre-class assignments. A short accountability quiz given at the start of class can

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be used to review key concepts from the pre-assignments. Similarly, if online homework is used for accountability checks, trouble spots in the homework can be used to review key points. Employing these accountability tools serves the dual purpose of reviewing needed material and communicating to students that the instructor is adapting classes to student needs. Additionally, students who did not complete the pre-class assignment now have an overview and still may be able to participate in the in-class work.

Peer instruction methods integrate well into the in-class segment of a flipped class format (*19*). Students are presented with a question they initially answer on their own, either through a class response system or by simply writing down an answer on paper. Then they are asked to discuss their answer with neighbors to try to reach a group consensus answer. Finally, potential answers are discussed with the entire class. A majority of students reaching the correct answer indicates the class can move on to the next problem. A wide variety of answers indicates that another explanation of the topic is warranted. Common misconceptions can be built into multiple-choice questions. This allows students to make the same errors they would in an open-ended format while using a simple response system.

Class response systems (e.g. iClicker, TopHat, Learning Catalytics) serve as excellent tools to engage students with questions and provide details about student responses (*20–22*). Careful analysis of the options for response systems should be carried out prior to selection of system. iClickers offer a device that does not require robust Wi-Fi infrastructure but is limited in answer types and incurs a significant cost to the students. Other options such as Learning Catalytics or TopHat rely on Wi-Fi and offer a range of question types but require students to have a mobile device or laptop computer in class. Learning Catalytics offers a much larger selection of useful tools specifically designed for the flipped classroom, but requires an additional student purchase on our campus where most students already use iClickers in other courses. For all internet-only systems, campus infrastructure must be equipped to handle the Wi-Fi usage. The final decision regarding what system to use is highly dependent on instructor and student preferences, campus infrastructure, and the nature of topics covered in the course.

In addition to problem-solving practice, in-class time can be used to provide demonstrations. Typically demonstrations are considered instructor-led modules. The in-class time previously used for content delivery in a traditional lecture format can be used in a flipped class format to introduce demonstrations with more student interaction. Additional time can be allotted for predictions, explanations, and discussions leading up to or resulting from the demonstration. Questions posed through a class response system or simple discussion with those willing to participate can be a valuable interactive experience because students have been introduced to the material in advance of the demonstration. Especially in science courses, demonstrations that include class interaction engage students with the material in a way attending lecture or reading independently cannot.

Recruiting helpers is essential to reach as many students as possible during in-class discussion time. With a student-instructor ratio of hundreds to one, the instructor simply will not be able to help each student or group of students individually. This is where graduate and/or undergraduate assistants can greatly

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enhance the success of a flipped class. Including assistants gives students more opportunities to interact with content experts. Both types of assistants can be trained to facilitate problem solving, guide groups of students in the right direction, and report common sticking points back to the instructor. If graduate teaching assistants are not available, undergraduate students trained in a manner similar to the Learning Assistant Program developed by the University of Colorado Boulder can be equally helpful (*23*).

A challenge we confronted in our initial flipped class attempts was addressing the wide variety of student levels present in the classroom. In a traditional lecture course, the lecture proceeds at a set pace that is too fast for some students and too slow for others. Students generally take notes diligently regardless of how the pace works for them. When class time is devoted to problem solving, these differences in student pace become glaringly apparent. While no single solution exists for this issue, we have tried a variety of approaches to provide some level of instructional differentiation. All problems for the day are provided to students as a PDF file before class time so students may download and/or print the packet if desired. Problems vary in difficulty, and students are made aware of which problems are ranked as easy, moderate, or challenging. Additionally, a few "super challenge problems" are included in each set. Students are reminded regularly that proficiency at easy and moderate problems will be the minimum needed to pass the class. Earning higher grades will require proficiency at correctly answering challenging problems and the ability to solve or at least begin parts of the "super challenge problems." However, students are not expected to solve the super challenge problems without some help. These are the problems that differentiate between the highest grades earned and grades that average performance warrants.

During class time, problems are worked at a moderate pace, but students who complete the current problem are encouraged to continue on without waiting for the rest of the class. Students who are consistently ahead of their peers are encouraged to work the challenge problems. Group or individual work is paused at regular intervals while the solution for the current problem is discussed and written out in detail. This class discussion allows common errors to be corrected promptly. The impact of the discussion is visualized instantly as the results from the response system are displayed in real time. Any problems which were not solved during class time have solutions posted on the class website. Solutions for "super challenge problems" are posted several days later to allow more time for students to work through them.

After Class

As part of our flipped class structure, students are required to complete post-class homework assignments within an electronic homework system. The quantity of problems in these assignments has been decreased in comparison to the assignments used in a traditional lecture class because students are completing so many more problems during a flipped class meeting. Due dates for these post-class homework assignments are set generally for one or two weeks after the material is discussed in class. More web-based homework problems are provided as optional practice problems. Additionally, students are provided with a list

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of textbook problems that they are encouraged strongly to complete for extra practice, but these are not required or graded in any way.

Students also attend discussion or recitation sections led by teaching assistants. In discussion sections, students are presented with a small number of challenging problems to be completed with a content expert teaching assistant present to help along when they get stuck or to redirect them when they are following an incorrect path. With so much time spent working on problems during the "lecture" portion of class, these discussion sections might be considered superfluous. This idea, however, ignores the benefit students will gain from additional structured time on task and from the much lower student-instructor ratio in discussion sections as compared to the full-scale "lecture" portion of the class.

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Flipped Classes in Traditional Classroom Spaces

Unfortunately, most instructors teach in classrooms that were not designed to accommodate classes that incorporate active learning strategies. Lecture halls with fixed, tablet-arm seating and single projection screens are designed for students to act as passive audience members rather than as active participants. In-class technology can help to minimize this challenge, but it does not replace spaces that are designed for students to work together. Despite these constraints, small group work can be accomplished in these less-than-ideal settings. For in-class work, consider assigning students to groups of three rather than allowing students to choose their own partners. This allows the three students to sit together in a row and collaborate without turning their backs to a group member. While outdated lecture halls are unavoidable for the time being, we should use the widespread adoption of active learning to advocate for a change in classroom design when remodeling old or constructing new instructional space. Many campuses around the country, including ours, are remodeling old-fashioned lecture halls or building new teaching spaces that are more conducive to active learning.

Additional Considerations for Flipped Classes of Any Size

Buy-In: Make or Break Your Class!

Some level of student resistance is to be expected any time a class is structured in a way new. Focusing on buy-in during the first day of class can help minimize students' reluctance to participate in a different type of class (*24–26*). In our experience, the best approach is to be transparent about how the class will be structured and why. Show students data that demonstrates the efficacy of active learning methods in general and flipped classes specifically. Address the student-held myth that flipped classroom methodology is just a way for instructors to be lazy. Students often have the perception that making some lecture videos in advance and then assisting students working on problems in class is less work for the instructor as compared to giving an expository lecture each day. Ask students

to consider the benefits to working through difficult concepts with the instructor present to assist them rather than struggling through these same problems alone later.

In addition to a general discussion about flipped classrooms, it is best to discuss specific instructor expectations. Students commonly believe they are expected to complete the in-class material without any assistance. This leads to unnecessary stress and strong resistance to the flipped style of teaching. Emphasize that while students are responsible for completing videos, readings, and pre-class assignments before class time, they are not expected to understand everything perfectly. Encourage participation during class meetings by pointing out that having questions about the material indicates students are well prepared for class.

Even with a very strong focus on buy-in from the beginning, some resistance to the flipped class model is usually present. An effective strategy to address this is to have a mid-quarter check-in time with students (*27*). A mid-quarter feedback survey is provided to students and time is set aside during class to discuss students' responses to the survey. This is a good practice in classes of any format, but we have found it to be an exceptionally useful opportunity to address any frustrations or difficulties students are having in transitioning to an alternative instructional method. Additionally, students are invited to share their tips and their difficulties with others. Occasional heated discussions occur between students regarding whether it is best to read the text before watching videos, watch videos before reading the text, or have the textbook open to the corresponding sections to intersperse bouts of reading during video viewing. This willingness to discuss the benefits and challenges of a flipped class is an excellent development. It shows that students are taking an active role in their learning and are considering what methods of content delivery work best for them personally.

Though student resistance is unavoidable, proper classroom management can minimize the effects on learning. While student attitudes can affect student evaluations of the course and instructor, this should not necessarily be considered negative, as often students must be taken out of their comfort zone to learn. We are currently investigating the effects of partially flipped classes for the first quarter freshmen who are particularly resistant to the methodology.

Effects of Student Experience Level on Attitudes and Efficacy

Several years of experience teaching flipped classes has elucidated some differences in how new college students versus those with some college experience perceive the class. Flipped classrooms are often a shock to young, inexperienced students. These students do not have the necessary study skills, motivation levels, or experience in learning to take full advantage of the flipped class methodology.

In the general chemistry classes, several different accountability measures for pre-class assignments were used simultaneously. The best approach for this particular group of students appeared to be a combination of targeted electronic homework questions asking students about important concepts in pre-class assignments and an in-class review quiz that included questions about the pre-class work. Anecdotal evidence suggested that many students still

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did not complete the pre-class work, choosing to obtain answers from friends instead. Therefore, pre-class homework and quiz questions were worded in such a way that the most important information was delivered simply by the students reading and answering the questions. Incorporating these methods mitigated non-compliance to some extent; despite these pre-emptive efforts, it was necessary to spend some class time reviewing the concepts in the pre-class work throughout the term. These brief reviews served a dual purpose. For the non-compliant students, they provided a brief "catch-up" period. For students who found the course more challenging than others, the reviews served to reiterate the material. Additionally, the review time opened up opportunities for questions from students who completed pre-class work and generally found the course of average difficulty but had areas of confusion. Unfortunately, the more prepared and higher performing students were frustrated by these reviews, necessitating the inclusion of the challenge problems previously discussed.

While some students in more advanced classes do resist the flipped classroom format, anecdotal evidence suggests the problem is less pronounced among more experienced students. Accountability checks for pre-class assignments were still necessary in the organic chemistry course, but students who did not come to class prepared were expected to catch up on their own. Occasional class discussions regarding students taking more responsibility for their own learning were integrated throughout the term to keep students on track.

If extensive student pushback should become an issue in a given class, a partially flipped model could be used as an intermediate point between a fully flipped class and a traditional lecture. In this model, less extensive forms of active learning are implemented two days per week, and a fully flipped format is included one day per week. Current studies exploring the effect of a partially flipped class are underway. Most students with a year or more of college experience, however, are ready to accept a fully flipped class format. A partially flipped experience in previous classes will lay the groundwork for acceptance of the full flip in subsequent years.

The preliminary research shows flipping chemistry classes is useful for many students. Although the magnitude of effect sizes in flipped classes with large enrollments or in classes lasting an entire term may not be not as sensational as those obtained when flipping smaller classes or only a few course modules, a net benefit is achieved for several student subsets, such as second year students, females, and repeating students. More research is needed to elucidate how to effectively reach students of all developmental levels with these techniques; longitudinal studies into the long-term effects of flipped classes throughout a student's education could identify outcomes beyond simple subject retention. Utilizing available technologies and assistants is essential to implementing a flipped classroom structure in a large enrollment course. Spending time to achieve student buy-in, developing homework assignments to reward compliance, and tuning the level of accountability requirements and flipped class material to one's particular student body can ensure a smooth transition for both students and instructor.

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Chapter 10

Experiences in Flipping a Large Lecture Course for General, Organic, and Biological Chemistry

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After years of using clickers in the classroom and seeing how even small amounts of active learning improved the classroom, flipping a class seemed to be the next step. To make the changes more manageable for me and for the students, I introduced weekly group activities into the course along with some on-line content to prepare them for the activity. I maintained half of my in-class time in a more traditional format with questions using a classroom response system. This encouraged students to think about the topic and work with neighbors to solve problems. This combination of teaching formats provides variety in the classroom, accommodates different types of learners, and allows me to teach the best way for a given topic.

Introduction

Chemistry for Health Professionals is a one-semester general, organic, and biochemistry (GOB) course for pre-nursing students with enrollment ranging from 200-270 students per semester The class is predominantly female (over 80%) and includes many non-traditional students, including some who currently work in healthcare, and veterans in the Med-Vet program (*1*). Admission to the nursing program is highly competitive so students are motivated to do well. They know an A or B is needed in the course to have a chance of being admitted. Students typically apply during their second semester of college and have only a few courses that contribute to their GPA. As a result, students are willing to work diligently and ask questions during and outside of class, often unseen in classes of this size.

Muzyka and Luker; The Flipped Classroom Volume 1: Background and Challenges
ACS Symposium Series; American Chemical Society: Washington, DC, 2016.

I chose to implement changes in this course for several reasons. On the practical side, there is only one section each semester and I teach it both semesters. This leads to continuity of content and teaching style. Additionally, this is a one-semester pre-requisite course for the nursing program but not for another chemistry course. This allows me to select topics that will best prepare students for their future courses in the College of Nursing. I have also found that the pre-nursing students are highly motivated and accept trying new things. While I would like to believe their motivation is based on their love of learning chemistry, it most likely stems from their desire to get into nursing school.

Logistics

There are no other instructors or teaching assistants in the room, therefore the size of the class leads to the biggest challenge in creating opportunities for active learning. I opted to split the class in half to make it more manageable, but this may not be transferable to other classes that have less frequent meeting patterns. This class is four credit hours and meets four days a week for 50 minutes each day. Splitting the class in half meant that all students came three days a week (half on Monday, half on Tuesday, and everyone on Wednesday and Thursday). Monday and Tuesday were known as "group days" where students worked on an activity during class with their group. On group days, there were clicker questions posted as well to monitor student progress through the activity and identify points of confusion that could be addressed to the entire class. These questions were open for students to answer for an extended period of time (5-15 minutes) so students could answer them when they had completed the indicated problem in the activity. I spent my time moving among groups to answer questions. If multiple groups had questions on the same topic, I would stop and give a mini-lecture on that topic. While it can be challenging to have so many groups at one time, there were a couple of strategies that helped manage the class beyond the mini-lectures. These included encouraging students to discuss questions in their group before asking me, editing activities for future semesters when there was a topic confusing to students, providing just in time resources such as links to videos for students to use in the classroom, and assigning seats to each group that left open paths from one side of the classroom to the other. Wednesday and Thursday were either regular class days, review sessions before an exam, or exams. The regular class days were traditional lectures but still had interactive elements in the class through extensive use of a classroom response system.

In preparation for each week's activity, students typically watched 2-4 Zaption lessons created from videos recorded by me or from other sources such as TED-Ed (*2*). The videos are usually 4-8 minutes and contained embedded questions (*3*, *4*). Each lesson was worth a few points to motivate students to complete them and to keep students accountable. None of the videos I created were perfect. Even with the imperfections, students definitely preferred those that I recorded over more polished lessons. The videos I record were usually screencasts recorded using the Explain Everything app, which allows me to add annotations and work example problems as if I were with the student (*5*). When I create videos, I try to think

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about how I would do something if a student were asking a question in class or sitting in my office. I try to recreate that environment as closely as possible.

In class, students worked on the activity with their group. Each group only received one copy of the activity to ensure that they worked together on it. Each activity consisted of one or more models containing data, graphs, or other details and a series of questions about the model. Initial questions were fairly straightforward reading of the data. Questions became progressively more challenging and required students to apply the concept to different scenarios. While completing the group activity, students answered questions through the classroom response system, which allowed me to gauge student understanding of a topic and monitor their progress through the activity while also making students accountable for class attendance.

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Group Structure

One of the most important aspects of my class structure was the formation and function of small groups. For pre-nursing students, I think it essential that they work in groups and that they do not choose their own partners. This mimics what they will experience when working in healthcare. I had two requirements for creating groups in the course. I wanted a way to create groups that would function well and a method for self and peer evaluation. I used CATME, a free online tool, to meet both of these objectives (*6*). At the beginning of the semester, students complete a brief survey with some basic demographic and attitude questions (Table 1) (*7*). The results of this survey were used to create the groups based on my priorities and student's needs. Groups were formed to combine students with similar characteristics (study hours per week outside of class, groups with one leader or consensus leadership) and dissimilar characteristics (math attitude, tendency to lead or follow in a group). Demographic questions were also available to create groups that have been shown to be more effective such as not outnumbering females or minorities in a group. With the high proportion of females in the class, gender balance was not as much of an issue but the option gave me flexibility I wanted. Survey and evaluation questions are preprogrammed into the system, although you can add additional questions. Setting up the initial survey and the groups based on the survey results usually requires 2-3 hours at the beginning of the semester. The evaluations during the semester take only a few minutes to setup and like any other feedback system, reviewing results can take as little or as much time as you choose to spend on it.

The last question listed in Table 1 was added after I attended two events. The first event was a workshop about the Med-Vet program where the Director of the Veteran's Resource Center on campus shared his experiences with student veterans over the years. One topic that resonated with me concerned seating arrangement in the classroom. While we often consider physical limitations for assigning seats, there may be other less visible limitations for some students. He shared stories of students who prefer to sit near an exit, in a location where they can see everyone in the room, or away from windows. While many students have a seating preference (front, rear, out of the line of sight of instructor, etc.), their

ability to participate in class and complete work may not be impacted because of an assigned seat. However, for some veterans, seating location could have a significant effect on their ability to concentrate and learn in the classroom. Asking this simple question addresses any student who has concerns about their assigned seat, including veterans. This is a better option than assuming that all veterans will need to sit in a certain location and deals with less visible issues that other student may have.

Table 1. Select Questions from Survey for Group Formation (*7*)

Question	*Answer Choices*
What gender do you identify with most?	- Male - Female - Other - Prefer not to answer
Rate how difficult you view math as a subject.	- Easy - Somewhat easy - Neutral - Somewhat difficult - Difficult
What is your preferred leadership role?	- Strongly prefer to be a follower rather than a leader - Prefer to be a follower, but will lead when necessary - Enjoy leading and following equally - Prefer to be a leader, but will follow when necessary - Strongly prefer to be the leader; do not enjoy being a follower
Please select the statement you most closely identify with	- I have more ideas in 5 minutes than most folks have all day, but hate to do the details - I prefer the idea phase but can do details - I am balanced between ideas and details - I prefer the details but can come up with ideas - While the visionaries are dreaming, I can get the project done and the report written
In this course, you intend to work how many hours per week outside of class (not counting lectures or labs)	- 1 hour per week - 2-4 hours per week - 5-7 hours per week - 8-10 hours per week - Whatever it takes
Do you have a physical disability or other issue which limits where you can sit in a classroom?	- Yes - No

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The easiest option is to let students pick their own seats, but attending the second event, a panel discussion on student perspectives from the classroom, made me change my mind. A wheelchair-bound student who has obvious limitations in where he can sit in many classrooms, especially auditorium- style rooms shared an experience from one of his classes. He was in a class where an instructor asked that the students form small groups to complete an activity but the room wasn't full and all the students migrated towards each other leaving the wheelchair-bound student sitting at the back of the room alone. Presumably, the instructor noticed this and resolved the issue but that results in a student who is already dealing with other challenges being singled out.

The CATME system provides an evaluation tool that includes self and peer evaluations, an important component to promoting positive group interactions and constructive feedback for improved group dynamic over time. The system includes guidance for students in evaluating themselves and peers. This guidance is important since many undergraduates do not have extensive experience in evaluating other students. After each of the three evaluation cycles during the semester, students have access to feedback from their group members with the information reported as an average of other students' responses. It keeps the feedback somewhat anonymous. However, groups of three means that while data was reported anonymously to students, the possibilities of who completed the evaluations on a particular student are extremely limited. Along with the evaluations, algorithms are used to identify under- and over-confident students. It also detects groups that may not be functioning effectively. Students receive suggestions on how to improve their group performance based on the feedback from other students. This method is far superior to sorting and distributing paper evaluations.

The self and peer evaluation system has a series of questions for students to rate themselves and their peers. Rather than assigning a numerical score to themselves, each question includes a rubric of behaviors that students may have experienced themselves or witnessed in other members of their group. Figure 1 shows an example of this system for one of the questions in the evaluation. It addresses how each person contributes to the team's work.

Student A completes her self-evaluation along with the peer evaluations for Students E and K. Upon completion, Student A will see her results as well as an average of how the other members of the group rated her. An example of the results is shown in Figure 2. Students can see how their self-evaluation compared to the evaluation of their work by peers. It provides specific descriptions of the rating, which is unique for each question. For each area of the evaluation, specific suggestions are given to improve their rating in that area. As an instructor, I have access to all student reports as well as the raw evaluation data.

Students do receive a grade based on the CATME survey and evaluations. The score for evaluations is based on a statistical value calculated as part of the evaluations system. For the overwhelming majority of students, this grade has little effect on their overall course grade. The students who are negatively affected are either those who do not complete the survey or evaluations (so they get a 0 on the assignment) or those who are frequently absent from class or are not prepared to complete the group activity in class. While some students will put forth their

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best effort to participate and learn regardless of grade, the CATME grade does encourage others, who need incentive, to be actively engaged in their group's work.

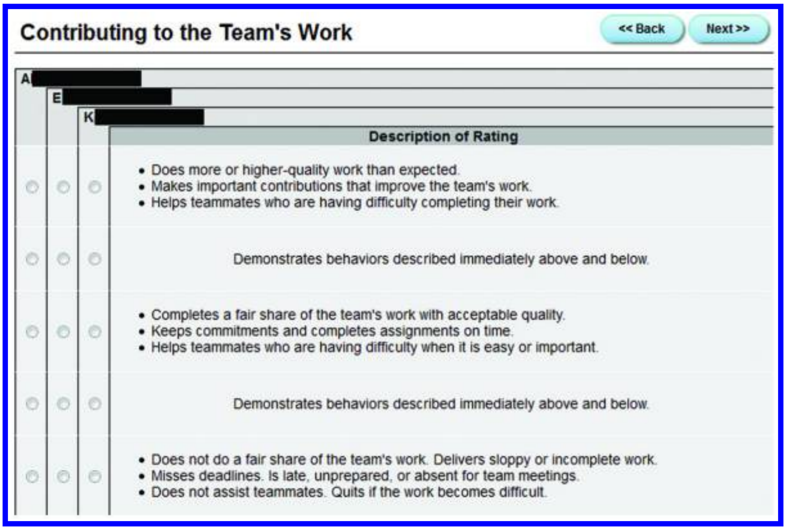

Figure 1. Self and Peer Evaluation Question. (CATME images reproduced with permission from reference (6). Copyright 2016 CATME.)

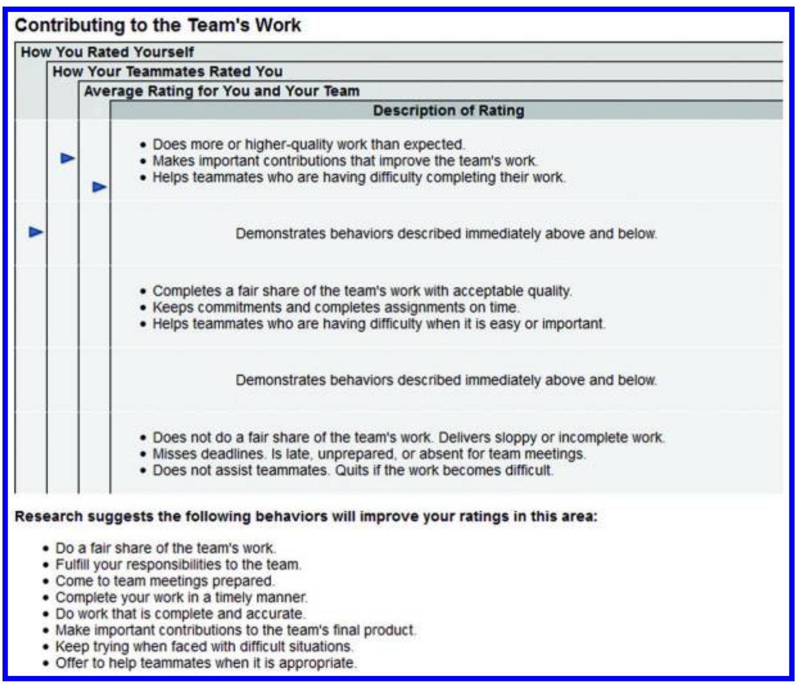

Figure 2. Results from CATME Evaluation. (CATME images reproduced with permission from reference (6). Copyright 2016 CATME.)

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Activities

The weekly activities covered topics that students had not seen at all or only had minimal coverage of in advance of class. Typically, the only coverage in advance was through the Zaption lessons (*1–3*). The activities are written such that they can get the knowledge they need to complete the questions through the information given in the activity itself. This activity was composed of models of worked problems, graphs, tables of data, or brief descriptions that were appropriate to the content. This has been a point of concern with students because they seem to think that the group activities are meant to practice skills they already know, which is what likely happened in their high school classes. An ongoing issue is the best way to "sell" this concept to the students so they understand the purpose and the structure of the activities. I don't feel like I've found the magic words, assuming they exist, so that students understand why we do the group activities and why they are structured the way they are. Like many other things in teaching, this is a work in progress.

Two other issues that have arisen during completion of the activities are students' failure to use the models provided to help them learn the concept and answer the questions, as well as skipping questions they don't understand. Neither of these approaches is useful in completing the activity since the models are necessary for learning the content and the questions are written to guide them through the content in a logical order. I think both of these habits come from the expectation that anything that looks like a worksheet is meant only to practice previously learned skills. They therefore believe that they shouldn't need to read the provided information. And, since it is for practice, the order doesn't matter. I hope that over time, students will see that learning comes from active engagement and not passively listening to someone talk.

I have authored most of the activities used in the course. Each semester, I try to make adjustments to them to provide a better learning experience for students. Sometimes that means adding a note to clarify (i.e. "R = chain of carbon atoms" for the functional group activity), choosing a different compound (i.e. NaCl instead of $NaNO_3$ when talking about oxidation numbers), or adding a worked example to model completion of a problem. Of course, some activities don't go as planned and rather than reusing something that didn't work, the better option is to try something new.

On group day, students pick up their group's folder containing the week's activity. At the end of class, they return the folder with the packet so I have the opportunity to review their progress and look for any areas where students struggled. They are encouraged to take a picture of the pages if they want to review their answers before the next week. A blank copy of the activity and an answer key are posted each week on our learning management system so they have access to the content soon after completion of their group day.

An example of an activity I created is shown in Figures 3 and 4. Typically, students have space to record their work and answers but the questions were condensed here for space. There were two Zaption lessons used as preparation for this activity (*2*, *3*). The learning outcomes for this activity were to identify the types of elements in ionic and molecular compounds, determine the charges

on ions in ionic compounds, and determine the formula for an ionic compound given the elements.

The first two questions were based on the given model and students' prior knowledge of how metals and nonmetals are arranged on the periodic table, straightforward questions that students sometimes got stuck on because they think the answer is more complicated than it really is. Adding in the possible answer choices (metals, nonmetals, metalloids) gave them an idea of what was expected for the answers. Then, they had the opportunity to apply that knowledge to other compounds.

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Ionic and Covalent Compounds

Table 1. Examples of Compounds

Ionic Compounds		Covalent Compounds	
NaCl	$LiNO_3$	CH_4	N_2O
$MgBr_2$	Na_2SO_4	C_2H_{10}	NO_2
$AlCl_3$	$Mg(OH)_2$	C_3H_8	N_2O_3
K_2S	$FeCl_2$	CO	PCl_3
CaO	$FeCl_3$	CO_2	SO_2

1. Look at the ionic compounds listed in Table 1. What types of elements (metals, nonmetals, metalloids) are found in ionic compounds?

2. Look at the covalent compounds in Table 1. What types of elements (metals, nonmetals, metalloids) are found in covalent compounds?

3. Which pairs of elements will form ionic compounds? Covalent compounds?
   a. cesium(Cs) and oxygen
   b. copper(Cu) and chlorine
   c. oxygen and sulfur
   d. chlorine and bromine(Br)
   e. hydrogen and sulfur

The formula for an ionic compound is based on the charges on the ions so that the number of electrons donated by the cation(s) will equal the number of electrons gained by the anion(s). Follow the QR code to hear an explanation of how the formula for that ionic compound is determined.

If you don't have a QR code scanner, search the appropriate app store for "QR" and you'll find numerous free options.

Example: potassium(K) and bromine (Br)
K loses one electron to become a cation with a 1+ charge.
Br gains one electron to become an anion with a 1− charge. So only one of each ion is needed to create a neutral compound.

Example: lithium(Li) and sulfur(S)
Li loses one electron to become a cation with a 1+ charge.
S gains two electrons to become an anion with a 2- charge.
Therefore, we need <u>two</u> lithium cations so that the total number of electrons lost by all lithium atoms is equal to the number of electrons gained by the sulfur atom.

Figure 3. Activity on Ionic Compounds, Part 1 (condensed for space).

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Example: magnesium(Mg) and oxygen(O)
Mg loses two electrons to become a cation with a 2+ charge. Oxygen gains two electrons to become an anion with a 2- charge. We need one Mg^{2+} ion and one O^{2-} ion to create a neutral compound, MgO.

4. What is the formula of the ionic compound formed from each of the following pairs of elements?
    a. sodium and chlorine
    b. calcium and nitrogen
    c. potassium and phosphorus
    d. strontium(Sr) and oxygen
    e. aluminum and sulfur

Many transition metals have more than one possible charge in an ionic compound unlike other metals. For example, iron can either be Fe^{2+} or Fe^{3+} and form $FeCl_2$ or $FeCl_3$.

5. What is the formula for the compound formed from
    a. Cu^{+} and oxygen
    b. Cu^{2+} and oxygen

Additional information has to be provided to know which form of iron is in the compound. This information can be either shown in the charge of the ion (i.e. Fe^{2+}) or in the formula of the compound (i.e. $FeCl_2$). The charge on the metal ion is "hidden" in the formula. Follow the QR code for a comparison of $FeCl_2$ and $FeCl_3$.

6. What is the charge on iron in each of the following compounds? For b and c, remember what the charge on oxygen <u>must</u> be.
    a. Fe_3P_2
    b. FeO
    c. Fe_2O_3

Figure 4. Activity on Ionic Compounds, Part 2 (condensed for space).

As the questions became more challenging to the students, additional information was needed. Rather than presenting this information at one time when not all students are ready for it, I provided worked examples through short (approximately 1 minute) videos linked through a QR code. Most students had a smartphone and could easily link to and watch the video, either individually as a group. The students were able to read a description of the problem, see it being worked, and hear a description of how to solve the problem. The hope is that by presenting information in multiple modes, students will gain a better understanding of the concept.

Beyond the Classroom

In addition to completing the preparatory activities, students also have other opportunities to engage with the material outside the classroom. We use an online homework system to provide students with additional practice, including feedback for wrong answers. This enables them to work and get some support at any time of day. Another tool that I rely on extensively is Piazza, which allows students to ask questions, receive answers from the instructor or another student, and gives

them the opportunity to answer other students' questions (*8*). When students help other students, it also reinforces the content for themselves.

Outcomes

Ideally, implementation of the group activities would lead to improved outcomes for students. Due to the gradual implementation of these changes, I was unable to collect data to demonstrate if the addition of the group activities improved learning on those topics. However, it is clear that course grades have not decreased. Since the changes were implemented gradually over multiple semesters, it isn't possible to isolate significant changes. With implementing multiple tools in a course, I have learned that it is essential to keep them organized both for yourself and for students. A brief introduction to each tool was given at the beginning of the semester. Each tool was accessed directly within the LMS or through a link from the LMS. Additionally, it has undoubtedly been more interesting to teach and pushed me to examine how and what I teach in the course, which has created a more relevant learning experience. However, not all students agree. The following student comments are typical examples from end of course evaluations.

> "[Group activities] forced me to look deeper into the text and thus understood it better."
>
> "The activities allowed us to put what we learned into practice and showed us whether or not we understood the topic."
>
> "I didn't like the groups, I would rather just have a lecture".

An interesting point about the third quote is that the student says they prefer lecture but do not state anything about learning. I suspect their dislike is due to the need to be engaged, especially when the class meets at 8:00 am in the spring semesters. In course evaluations, I continue to see positive as well as a few negative comments. The negative remarks typically center on the idea that they would learn more if I just lectured four days a week. As is well known, this is usually not the most effective way to learn new material. Additionally, three-fourths of students repeating the course preferred the use of the group activities and videos over a class taught through lectures (while responding to questions via the classroom response system).

Future Plans

Improving student engagement and learning in the classroom will not happen overnight. My future plans include recording more videos to replace some from other sources. I would also like to record additional videos and write additional activities so that I can completely flip the classroom. I believe that I can continue to improve student experiences and outcomes for the course. Doing a complete flip

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of the course is my ultimate goal but development of quality activities requires significant effort and time, which is not always available.

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2. *Zaption* (www.zaption.com) is an online tool that allows users to integrate questions with a video from any source. A paid subscription allows for integration with your LMS creating a seamless presentation of a lesson and recording of grades (accessed May 24, 2016).
3. Zaption Lesson "Electron arrangements". http://zapt.io/twdb8vfs (accessed March 1, 2016).
4. Zaption Lesson "Ion formation" http://zapt.io/tmn4w3va (accessed March 1, 2016).
5. *Explain Everything* (www.explaineverything.com) is an app available on iOS, Android and Windows which can be used for screen casting. It allows for the import of slides, images, and other media so you can easily record audio and annotation of the content on the screen. Enough editing features to be useful, but not so many that it is overwhelming (accessed May 24, 2016).
6. *CATME* (www.catme.org) is a research-based system that provides tools for assigning students to groups and self and peer evaluation of the resulting groups. Groups are formed based on survey responses for questions you choose with the priorities you find most important. The self and peer evaluations provide a straightforward way to collect feedback and disseminate the information anonymously to group members (accessed May 24, 2016).
7. Ohland, M. W.; Loughry, M. L.; Woehr, D. J.; Bullard, L. G.; Felder, R. M.; Finelli, C. J.; Layton, R. A.; Pomeranz, H. R.; Schmucker, D. G. The comprehensive assessment of team member effectiveness: Development of a behaviorally anchored rating scale for self and peer evaluation. *Acad. Manage. Learn. Educ.* **2012**, *11*, 609–630.
8. *Piazza* (www.piazza.com) replaces the ineffective discussion boards found in many LMSs and saves instructors from having to answer the same question multiple times via email. Students can post questions which are then answered by students or instructors with responses from both clearly marked. It allows for follow-up questions, instructor editing of all content, and a "stamp of approval" by the instructor for a good answer from a student (accessed May 24, 2016).

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Jennifer L. Muzyka received her B.S. from University of Dallas and her Ph.D. in organic chemistry from University of Texas, Austin. She began her college teaching career at Roanoke College. Later she moved to Centre College in Kentucky, where she is currently H.W. Stodghill Jr. and Adele H. Stodghill Professor of Chemistry. Muzyka leads workshops on Active Learning in Organic Chemistry and serves on the leadership board for OrganicERs, an online community for organic chemistry educators (http://organicers.org). She also serves on the ACS Division of Chemical Education's Committee on Computers for Chemical Education, currently as committee co-chair.

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Christopher Luker received his B.S. in chemistry from Allegheny College and his M.A. in Education from The University of Akron. He currently teaches college-preparatory and Advanced Placement chemistry at Highland High School in Medina, Ohio. He has been involved in flipped classroom pedagogy since 2008 and has been involved in numerous local, regional, and national events on the flipped classroom. Even though he was not the originator of the concept, Luker was part of a very small group that introduced the flipped concept to the Biennial Conference on Chemical Education in 2012. Luker is currently a doctoral student at Kent State University, where his research interests are related to the metacognitive aspects of the flipped classroom experience.

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